Evaluation of New DHW System Controls in Hospitality and Commercial Buildings

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Definition of Terms and Acronyms

CBECS: Commercial Building Energy Consumption Survey

CDHW: Central domestic hot water

CEC: California Energy Commission

CEE: Center for Energy and Environment

CEUS: Commercial End Use Survey

EUI: Energy Use Intensity

HDD: Heating degree day

HVAC: Heating, ventilation, and air conditioning

GTI: Gas Technology Institute

Executive Summary

Background

The energy usage of hot water systems in non-residential facilities is often overlooked. Hot water systems, particularly large central systems, are typically among the larger systems in a commercial building. In Minnesota's climate, however, they are a much lower priority than space heating systems. This presents an opportunity for system improvement and energy savings.

Hot water usage patterns in hospitality, commercial, and multifamily applications tend to reflect periods of heavy use (weekday mornings and early evenings), as well as periods of low or no use (between midnight and 5 a.m.). To ensure that hot water is immediately available at all times, building owners typically install central recirculation loops that operate continuously, even during periods of low or no use. This results in continuous circulation pump electricity consumption, as well as wasted energy to constantly reheat water as it circulates through the building.

To limit these pump and reheat costs, building managers often use aquastat and time clock recirculation loop controls. However, because the controls work on schedules preset for low use, hot water draws are significantly delayed during periods when the pump is off. When occupants complain about the delays, building managers often bypass or remove the time clock-based controls. In the hospitality sector, where guests' hot water usage patterns are particularly unpredictable, managers are left with little choice beyond continuous recirculation to avoid risking customer dissatisfaction.

Unlike crude traditional controls, the new demand systems use temperature and demand inputs, so the controller activates recirculation when both (a) the recirculation loop return water has dropped below a prescribed temperature and (b) a DHW demand is sensed as water flow into the system. Demand controls respond more quickly to deliver hot water during low use periods, resulting in greater building manager acceptance and persistent savings.

Research Methodology

Although on-demand hot water recirculation technology has been demonstrated in other states, it has primarily been within the multifamily sector. A field-based quantification of the technology within other commercial building types had not previously been performed in Minnesota. This project characterized demand controllers in Minnesota, specifically for hospitality and commercial buildings. This characterization supports incorporating this technology into Minnesota's Conservation Improvement Program by answering the following questions:

- What are the energy savings of the demand control system versus the baseline (24/7) system?
- What percentage of reduction in pump run time occurs in demand mode versus the baseline (24/7) scenario?

- How are the energy savings affected by changes in the inlet water temperature (i.e., seasonality)?
- How satisfied are occupant and building owners with the hot water delivery?
- What was the experience for installation contractors with this technology?

Commercial and hotel properties were recruited for the field study primarily from contacts in a range of research projects and consulting work in these building sectors. Buildings were targeted based on their fit for demand-based controller application. These characteristics included hot water usage distributed throughout the building, centralized DHW systems, and recirculation loops.

Site visits were conducted to collect information on each recruited building, including overall building size and use, hot water heating and distribution system equipment and design, the types and locations of end use fixtures, and baseline system operating parameters. The initial plan called for a short data collection period at 10 buildings to characterize the recirculation pump runtime and water temperatures within the DHW system.

Based on the building and system information and data collected at each potential building, a subset of six buildings was targeted for the full field evaluation. These six sites included two middle schools, one capitol administration building, and three hotels.

A demand controller and data monitoring equipment were installed at the six field sites. Data analysis focused on an evaluation of the savings potential of demand controllers in a range of commercial applications.

An alternating mode test was then conducted for at least 10 months; the controller was alternated between the on and off mode to capture baseline and controlled data in all seasons. The alternating mode test design was used to ensure that data was collected under the full range of operating conditions in both controlled and baseline operation modes. In this way, the project team was able to consider not only average performance, but also the impact of seasonality on performance.

In addition to annual energy savings, several secondary impacts were also assessed and analyzed to understand the impact of the controller on the system and building performance. Water temperatures and flow rates were used to understand the impact on delivered water temperature and the potential impact on space conditioning loads due to heat losses from the water heating system.

Results

Due to operational logistics, a full analysis was completed at only four of the six sites. The results for these sites (Table 1) show consistent positive savings. On average, 13% of the energy to heat water and 87% of pumping energy was saved.

Table 1. Annual energy savings for each field site

Mode	Measurement	Hosp_02	Hosp_03	Ed_02	Com_03 [b]	Average
Baseline	Thermal Use (therms)	9,965	8,211	415	1,439	5,008
	Electrical Use (kWh)	3,679	675	830	3,241	2,106
	HW Used (gal/day)	3,210	1,822	165	74	1317.75
	Operating Cost [a]	$9,945	$7,888	$503	$5,903	$6,060
Control	Thermal Use (therms)	8,979	6,907	368	1,147	4,350
	Electrical Use (kWh)	1,104	47	32	389	393
	HW Used (gal/day)	3,210	1,822	165	109	1326.5
	Operating Cost [a]	$8,674	$6,568	$354	$4,420	$5,004
Difference	Thermal Use (therms & %)	986	1,304	47	292	657.25
		9.9%	15.9%	11.4%	20.3%	14.38%
	Electrical Use (kWh & %)	2,575	627	799	2,852	1,713
		70.0%	93.0%	96.2%	88.0%	86.80%
	HW Used (gal/day & %)	0	0	0.2	35	8.8
		0%	0%	0%	32%	8%
	Operating Cost ($ & %) [a]	$1,271	$1,320	$149	$1,483	$1,056
		12.8%	16.7%	29.6%	25.1%	21.05%

a. Natural gas price of $0.95/therm and electricity price of $0.13/kWh, based on the average pricing from the Energy Information Administration (US EIA 2014).

b. Com_03 had an electric water heater.

While the percentages saved are relatively consistent, the total energy and cost savings vary widely with hot water load. Buildings with high water usage have bigger DHW systems, bigger pipes, and higher flow rate. These larger systems have higher losses and more potential for savings.

The cost effectiveness of these installations depends on the overall water heating load. The installation costs were relatively consistent across the six sites. For sites with one flow sensor, as will be the case on the vast majority of the jobs the average installations were completed in about 4 hours and cost was $887[1]. The controller and control sensors cost $1,095. For the single site that used three flow sensors the installation cost was not significantly different, but the sensors and controller cost $1,635. All six installations used the existing recirculation pump. The manufacture noted that for some installations a new pump may be necessary. For these installations a pump and controller package can be purchased

[1] This install cost did not include any additional contractor or project staff time for troubleshooting or commissioning issues found in the DHW systems or controller installs. The $887 does include some non-labor costs, including materials.

for a cost of $1,395 to $1,900 depending on the required pump. The average total installed cost for this project was $2,072

The project average simple payback for DHW recirculation demand control was 1.7 years. The hospitality properties had much larger hot water loads and therefor had shorter paybacks, between 1.0 and 2.1 years. One of the commercial properties used an electric water heater, despite significantly less hot water use the payback was still less than 2 years due to the higher cost per Btu of electricity. The commercial site with a natural gas water heater had the lowest water use and the inexpensive cost of natural gas resulted in a payback just over 10 years.

Hot water use significantly impacts each building's savings potential. As with the hotels monitored in this project, buildings that use 1,500 or more gallons of hot water a day should see paybacks around two years. Buildings using much less hot water, such as the office and education building monitored in this project, save significantly less energy per year, resulting in longer paybacks (Table 2). And buildings with electric water heating, like Com_3 in this study, save the same amount of energy, but with greater cost savings and shorter paybacks due to the higher costs of electric water heating.

Table 2. Simple paybacks for demand controlers for average field characterization results

Building	Hot Water Use (GPD)	Annual Savings	Install Cost	Payback (years)
Hotel: Typical install	>1,500	$1,300	$1,715	1.3
Hotel: Complex Install	>1,500	$1,300	$2,097	1.6
Commercial	<200	$400	$1,715	4.3
Commercial: Electric WH	<200	$900	$1,715	1.9

a. Note that installation costs, savings, and paybacks for both the commercial and commercial electric water heater results are based on the averaged performance of Com_Ed_2 and Com_3. For example for the gas water heater average the results from Com_3, which had an electric water heater, were estimated had the water heater used natural gas instead.

Conclusions and Recommendations

Both in natural gas and electricity use, savings achieved by this project were significant enough to include this technology in Minnesota's Conservation Improvement Program, but installation and operation of these controls can be difficult in more complicated system designs. Offerings designed to facilitate the installation of a DHW recirculation controller should consider the best market segments to ensure cost-effectiveness. The following criteria will ensure a good performance and significant energy savings.

1. Hot water should be supplied through a central DHW system.
2. The central systems' distribution should use a recirculation loop or loops with continuous operation for at least eight hours per day.
3. The central DHW systems should use at least 500 gallons of hot water per day.
4. The controller manufacturer's installation documentation should be followed, including control sensor placement location and controller operation parameters. For unique installations that must deviate from the recommended installation, the manufacturer or a manufacturer-approved installer should be consulted.
5. Building operators and the installing contractor should know and understand the DHW system design, distribution loop, fixtures, operating conditions, and system heat source (water heater). In more complex DHW systems, it is necessary for the installer to understand the flow paths and plumbing design to ensure the sensors are measuring in the correct locations. For example if a recirculation system has multiple zones and the recirculation pump on the first zone is controlled, the second zone can keep a shared recirculation return line warm, preventing the controller from turning on the pump in the first zone, resulting in cold water.
6. The DHW system should be tested for pre-existing issues prior to installation of an advanced controller. Hot water system issues, such as cross-over and unbalances recirculation zones, can be hidden by the large hot water wastes in continuous recirculation. Eliminating the waste with a demand controller can highlight and expose these problems.

Meeting these six criteria will result in a straightforward installation that yields significant energy savings, delivers adequate performance, and has a good payback. Once a quality installation is performed, the deemed energy savings can be estimated with a simple calculation for each fuel type.

Thermal Energy Savings

$$Annual\ Thermal\ Savings\ (MMBtu) = C_m * C_u * GPD_h * 365 * \left(T_{Supply} - T_{main}\right) * \left(\frac{1}{eff_{syst}}\right) * RT_{frac} * Sav_{thermal}$$

Where

C_m = a materials constant for the properties of water = 8.3

C_u = a unit conversion factor = 1/1,000,000

GPD_h = daily hot water volume in gallons, if unknown, see Table 3.

T_{supply} = hot water supply temperature = 125 ^{o}F

T_{main} = main water temperature incoming to the building = 60 ^{o}F

Eff_{sys} = system efficiency accounts to the water heater efficiency as well as the distribution efficiency = 0.55

RT_{frac} = fraction of the day the recirculation pump is running in baseline mode

$Sav_{thermal}$ = the estimated thermal savings for the demand controller, based on the results from this project = 12%

Table 3. Hot water Use for Various Types of Buildings (ASHRAE 2015)

Type of Building	Average Daily Use
Motels:	
20 units or less	20 gal per unit
60 units	14 gal per unit
100 units or more	10 gal per unit
Office Buildings	1 gal per person
Elementary Schools	0.6 gal per student
Junior and Senior high schools	1.8 gal per student

Electrical pump savings

$$Annual\ Pump\ Savings\ (kWhr) = C_u * P_{pump} * RT * 365 * RT_{frac} * Sav_{pump}$$

C_u = a unit conversion factor = 1/1,000

P_{pump} = pump energy consumption in Watts, if known assume 125 W

RT = hours of the day the recirculation pump is running in baseline mode

RT_{frac} = fraction of the day the recirculation pump is running in baseline mode = RT/24

$Sav_{thermal}$ = the estimated pump savings percentage for the demand controller, based on the results from this project = 87%

Background

Introduction

The energy usage of hot water systems in non-residential facilities is often overlooked. Hot water systems, particularly large central systems, are typically among the larger systems in a commercial building. In Minnesota's climate, however, they are a much lower priority than space heating systems. This presents an opportunity for system improvement and energy savings.

Hot water usage patterns in hospitality, commercial, and multifamily applications tend to reflect periods of heavy use (weekday mornings and early evenings), as well as periods of low or no use (between midnight and 5 a.m.). To ensure that hot water is immediately available at all times, building owners typically install central recirculation loops that operate continuously, even during periods of low or no use. This results in continuous circulation pump electricity consumption, as well as wasted energy to constantly reheat water as it circulates through the building.

To limit these pump and reheat costs, building managers often use aquastat and time clock recirculation loop controls. However, because the controls work on schedules preset for low use, hot water draws are significantly delayed during periods when the pump is off. When occupants complain about the delays, building managers often bypass or remove the time clock-based controls. In the hospitality sector, where guests' hot water usage patterns are particularly unpredictable, managers are left with little choice beyond continuous recirculation to avoid risking customer dissatisfaction.

Unlike crude traditional controls, the new demand systems use temperature and demand inputs, so the controller activates recirculation when both (a) the recirculation loop return water has dropped below a prescribed temperature and (b) a DHW demand is sensed as water flow into the system. Demand controls respond more quickly to deliver hot water during low use periods, resulting in greater building manager acceptance and persistent savings.

Justification

Opportunity in the Hospitality and Commercial Sector

The Minnesota hospitality sector has continued steady growth since the end of the economic recession in 2011. The supply of rooms increased by 1.4% in 2014 alone (Explore Minnesota, 2015). There are a total of 2,536 accommodation establishments in the state, representing 13.3% of the total number of leisure and hospitality facilities in Minnesota (Minnesota Department of Revenue, 2013a). The distribution of hospitality establishments, along with gross sales are shown in Table 4 (Minnesota Department of Revenue, 2013a).

Table 4. Snapshot of Hospitality Establishment Distribution and Gross Sales in Minnesota, 2013

Region	# of Hospitality Establishments	% of Total	Gross Sales	% of Total
Central Minnesota	540	21.6%	$245,444,737	11.6%
Minneapolis-Saint Paul	507	20.3%	$1,195,419,915	56.7%
Northwest	462	18.5%	$164,179,513	7.8%
Southern	437	17.5%	$267,450,779	12.7%
Northeast	552	22.1%	$234,940,150	11.1%
Total Minnesota	2,536[a]	-	$2,107,435,094	-
Total U.S.	52,887[2]		$163,000,000,000[2]	

b. The total of the regional columns is 2,498; however, there are a small number of establishments that were only accounted for at the state level and were not included in the regional breakdown. As such, the total reflected in this table is the correct statewide total, though it will not reflect the sum of the regional totals.

Although the distribution of establishments does not vary widely between regions, the gross sales are vastly dominated by hospitality establishments within the Minneapolis-Saint Paul area.

Table 5. Snapshot of Other Commercial Sub-Sectors in Minnesota, 2013

Industry	Industry Code	# of Establishments	Gross Sales
Colleges, Universities, and Professional Schools	6113	102	$1,017,361,177
Nursing, Mental Health & Residential Care Facilities	6230, 6231, 6232, 6233, 6239	482	$851,180,577
Outpatient Care Centers	6214	421	$1,292,406,878
Food Service	7220, 7221, 7222, 7223	9,919	$7,716,308,910
Retail Stores	4511, 4512, 4520, 4521, 4529, 4531, 4532, 4533, 4539	18, 016	$20,001,681,477

Source: Minnesota Department of Revenue, 2013b.

Other commercial businesses (such as retail stores, food service, and nursing homes) may have more total establishments in Minnesota, but hospitality is considered an ideal next-step market for on-demand hot water controls — which have already seen growing adoption within the multifamily sector.

[2] American Hotel & Lodging Association. 2013. 2014 Lodging Industry Profile (all figures are for year-end 2013). (http://www.ahla.com/content.aspx?id=36332). Accessed July 22, 2015.

Nonetheless, depending on hot water usage patterns, there are sub-sections within the larger commercial sector that can benefit from early adoption of on-demand hot water controls. Table 5 shows details about the commercial businesses that have the greatest likelihood of benefiting from early market adoption of on-demand hot water controls. This list is not intended to be exhaustive for all the commercial businesses that could yield significant energy and cost savings from adopting some form of hot water controls; it includes businesses that are considered to be the best candidates for early market adoption.

Although energy use intensities (EUIs) are not publicly available for buildings across Minnesota, the City of Minneapolis adopted ordinance 47.190 in February 2013, which mandates that privately-owned commercial buildings with 50,000+ square feet and public buildings with 25,000+ square feet must benchmark their energy and water use on an annual basis and report their findings to the city. As this is a relatively recent requirement, the ability to see long-term trends is limited. Although the EUIs are only for buildings within the City of Minneapolis, it is still a useful representation of how commercial buildings perform on an energy efficiency basis across the state.

Figure 1. Property Types for Benchmarked Commercial Buildings, by Count

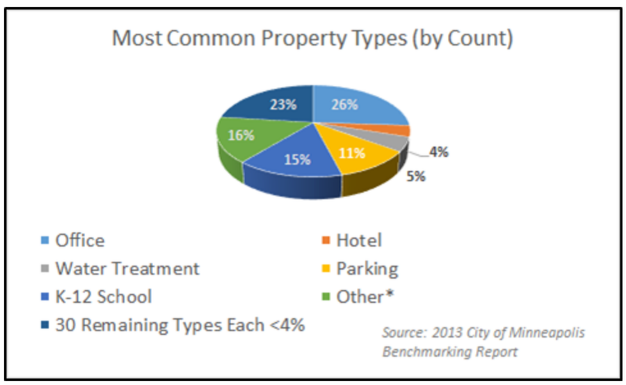
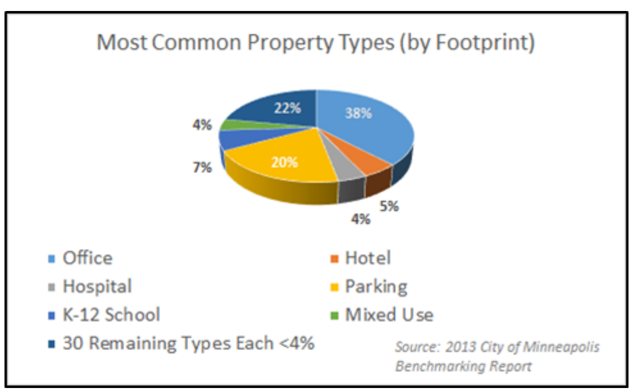


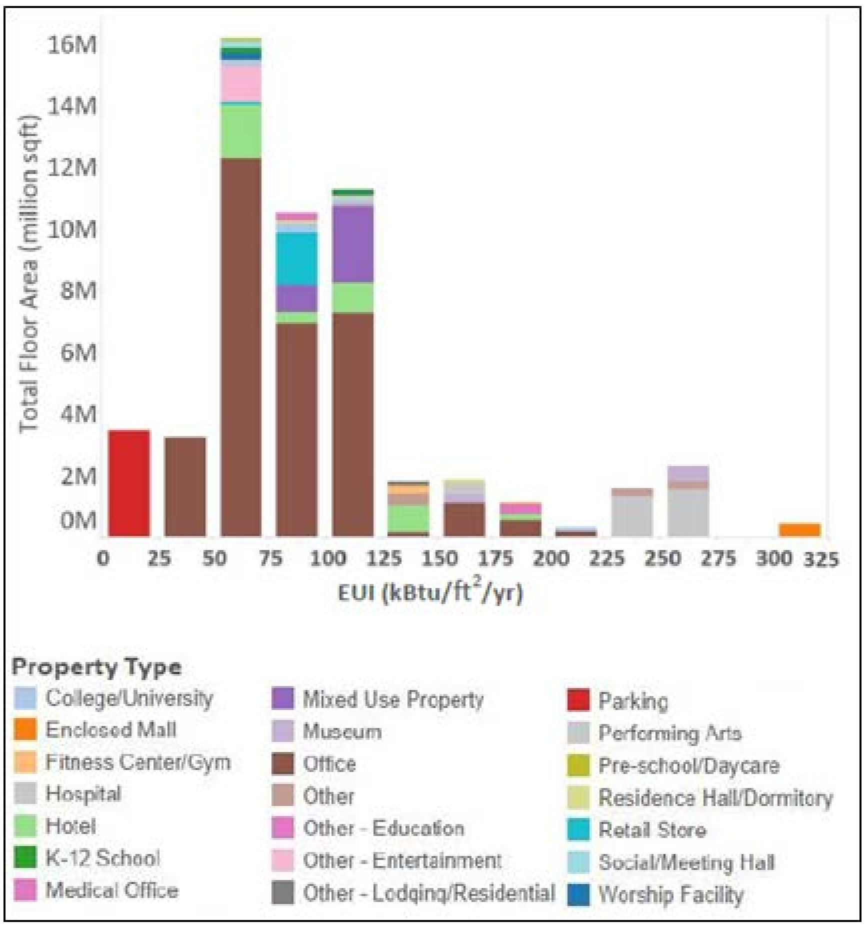
Figure 2. Property Types for Benchmarked Commercial Buildings, by Footprint



The 2013 benchmarking report included a total of 365 large commercial and public buildings (194 private and 171 public buildings). Figure 1 and Figure 2 show the most common building types that reported, both by building count and total footprint area; office buildings represent the largest portion of both.

The City of Minneapolis' findings reflect the wide-range of EUIs that can occur for buildings with the same end use (Figure 3). Daily and weekly usage patterns, occupancy rates, maintenance and replacement schedules of HVAC equipment, and many other factors influence energy use intensity. Hotels and other lodging properties display EUIs varying from 50 up to 200 kBtu/sf/yr, indicating certain properties may have a chance for notable energy savings. Unfortunately, most of the other business types targeted for early market adoption of on-demand hot water controls are minimally represented in these figures. Nursing and residential health care facilities are not separated out within the graphs and cannot be differentiated from the hospital or medical office categories. Residence halls/dormitories and fitness centers/gyms will likely have the type of hot water usage patterns similar to multifamily housing, and thus may be good targets; however, not many private buildings within that category were benchmarked in the City of Minneapolis Benchmarking Report, 2013. Due to the minimum square footage to trigger benchmarking requirements by the City of Minneapolis, food service establishments are not shown in Figure 3. Fast food and traditional restaurant dining facilities very rarely exceed 50,000 square feet. Unfortunately, further mining of the detailed data behind these charts is limited because the City of Minneapolis only releases the detailed dataset for the public buildings and not the privately-owned buildings.

Figure 3. Cumulative Private Building Property Type Area by EUI in the 2013 Energy Benchmarking Report



Limited public information is readily available and minable regarding key characteristics of buildings across the state. Two of the most recent studies that have included information on commercial building vintages include the 2013 Energy Benchmarking report by the City of Minneapolis and the 2012 Commercial Building Energy Consumption Survey (CBECS) by the Energy Information Administration (EIA). While the City of Minneapolis's report is limited to a small, relatively urban dataset, the EIA analysis includes all commercial buildings within the West North Central census region and division. The West North Central division includes: North and South Dakota, Nebraska, Kansas, Missouri, Iowa, and Minnesota. The 2013 Benchmarking report showed relatively consistent results for many vintages, with the exception of Minneapolis reporting over double the amount of buildings constructed in 1970-1979 and 90% fewer buildings constructed pre-1920. Other key building characteristics that are included in the 2012 CBECS dataset include number of stories and total square feet, which are shown in Table 6 and Table 7.

Table 6. 2012 CBECS West North Central Region Commercial Buildings by Number of Stories

Number of Floors	Number of Buildings (thousand)	% of Total
One	317	63.1%
Two	124	24.7%
Three	48	9.6%
Four to Nine	13	2.6%
Ten or More a		

a. Data withheld either because the RSE was greater than 50% or fewer than 20 buildings were sampled.

Source: 2012 EIA Commercial Building Energy Consumption Survey

Table 7. 2012 CBECS West North Central Region Commercial Buildings by Floorspace

Building Floor Space (square feet)	Number of Buildings (thousand)	% of Total
1,001 to 5,000	273	54.4%
5,001 to 10,000	113	22.5%
10,001 to 25,000	68	13.5%
25,001 to 50,000	27	5.4%
50,001 to 100,000	14	2.8%
100,001 to 200,000	4	0.8%
200,001 to 500,000	2	<0.5%
Over 500,000	<0.5	<0.5%

Source: 2012 EIA Commercial Building Energy Consumption Survey[3]

[3] U.S. Energy Information Administration. 2012. Commercial Building Energy Consumption Survey. (http://www.eia.gov/cbecs)

Savings Potential for On-Demand Hot Water Technology

Based on savings levels seen in past multifamily field testing and manufacturer claims, the following theoretical and technical savings level scenarios were calculated:

1. Theoretical: 100% adoption within select commercial building types
2. Technical: Adoption rate of 10% only within the hospitality sector

Based on compiled datasets from California, Illinois, and Michigan for the installation of on-demand pumps in multifamily buildings, approximately 1,484 therms and 1,230 kWh can be saved per pump on an annual basis (Gas Technology Institute 2014). Other select early adoption markets likely have similar hot water draw profiles to multifamily, including hospitality, dormitories, and residential nursing homes (Table 8). Each of these facilities have hot water usage patterns that reflect residential activities – such as showering, laundry, and cooking.

Table 8. Preliminary Theoretical Savings Potential of On-Demand Controls in Select Commercial Building Types

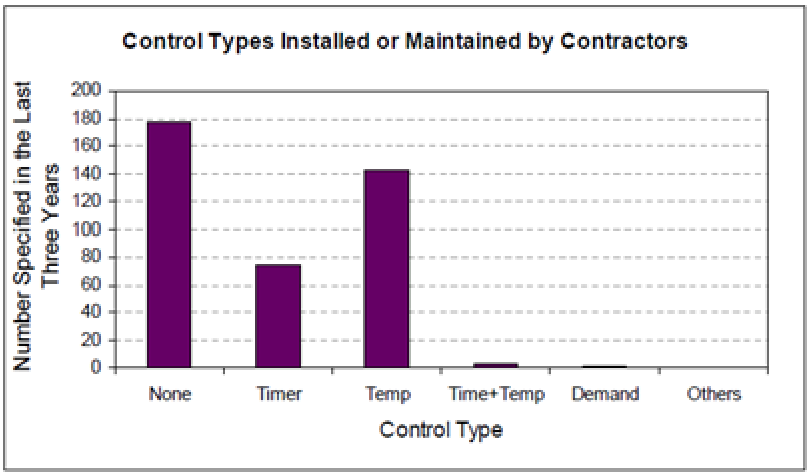
Type of Establishments	Number of Establishments	Market Penetration	Total Annual Gas Savings (therms)	Total Annual Electric Savings (kWh)
Hospitality	2,536	100%	3,763,424	3,119,280
Colleges, Universities, & Professional Schools	102	100%	151,368	125,460
Nursing, Mental Health & Residential Care Facilities	482	100%	715,288	592,860
TOTAL	3,120		4,630,080	3,837,660

Food service and retail stores have different trends in hot water draw profiles and therefore will provide different savings levels. Unfortunately, no field testing or modeled results are readily available for the deployment of on-demand controls within these types of end uses. Food service will have a larger total hot water demand than retail or office applications; though they are likely to have a more compact distribution system. Most food service facilities do not employ hot water controls because immediate hot water must be available at all times for kitchen and wait staff, per health and safety standards. As such, on-demand controls may offer a unique opportunity to provide hot water whenever it is needed, but capture savings in between heavy use periods.

Retail stores have very low hot water demand, typically strictly handwashing, resulting in modestly sized water heaters and very basic distribution systems. Although savings on a percentage basis may be similar to what has been recorded in multifamily applications, the total energy savings will likely be notably lower. Retail applications are likely to be a third-tier target for the expansion of this technology.

Of course, full market penetration cannot be expected, even if this technology were to become the code minimum in Minnesota. It must be assumed that economic circumstances will come into play at each individual site. Research regarding the frequency of hot water control types used in multifamily or commercial buildings specific to the state of Minnesota is not available. However, a detailed study of water heaters and hot water distribution systems within the state of California reported interesting findings regarding the market penetration of different hot water control strategies. Figure 4 shows responses from contractors regarding the prevalence of central hot water distribution system control types they've either installed or maintained within the previous 12 months (California Energy Commission and Lawrence Berkeley National Laboratory 2008).

Figure 4. Control Types Installed or Maintained by Contractors in California



As can be seen, the installation of no controls appears to be the most common, followed by the installation of temperature controls, and then timer controls. Pre-combined temperature and time controls are less common and demand-based controls were only seen in a handful of instances. It should be noted that this detailed survey was performed in 2008, and since that time, demand controls have been heavily pushed by the state of California. Most recently, the California Energy Commission passed final approval on the Title 24 Energy Efficiency Building Codes update, which includes demand controlled recirculation as a prescriptive baseline.

Given the relatively low rate of ANY control being implemented on central hot water distribution systems, a more realistic market penetration rate should be assumed for our purposes of assessing the energy savings potential of on demand controls with the Minnesota commercial sector. A 10% adoption rate still reflects a strong market and total energy savings potential of 461,524 therms and 382,530 kWh across Minnesota (Table 9).

These represented the project team's best conservative estimates at the start of the project about the realistic savings potential of this technology within select applications in the Minnesota commercial sector. Following the field testing, refined estimates of the savings potential may be developed.

Table 9. Preliminary Technical Savings Potential of On-Demand Controls in Select Commercial Building Types

Type of Establishment	Number of Establishments	Market Penetration	Total Annual Gas Savings (therms)	Total Annual Electric Savings (kWh)
Hospitality	253	10%	375,452	311,190
Colleges, Universities, and Professional Schools	10	10%	14,840	12,300
Nursing, Mental Health & Residential Care Facilities	48	10%	71,232	59,040
TOTAL	311		461,524	382,530

Previous Work

Although the demonstration, monitoring, and analysis of the use of on-demand central domestic hot water (CDHW) recirculation systems has not been completed in the State of Minnesota before, there is related previous work that helped inform the project team's expectations and approach for this project. A first priority in this was to see what data and research were available on commercial sector water consumption patterns.

The 2012 Commercial Building Energy Consumption Survey (CBECS) conducted by the U.S. Energy Information Administration shows that the west north central census region and division consumed a total of 19 billion cubic feet of natural gas for water heating, representing about 13% of total natural gas use in that division. This equates to a natural gas energy intensity of 7 kBtu/sf for commercial buildings overall.

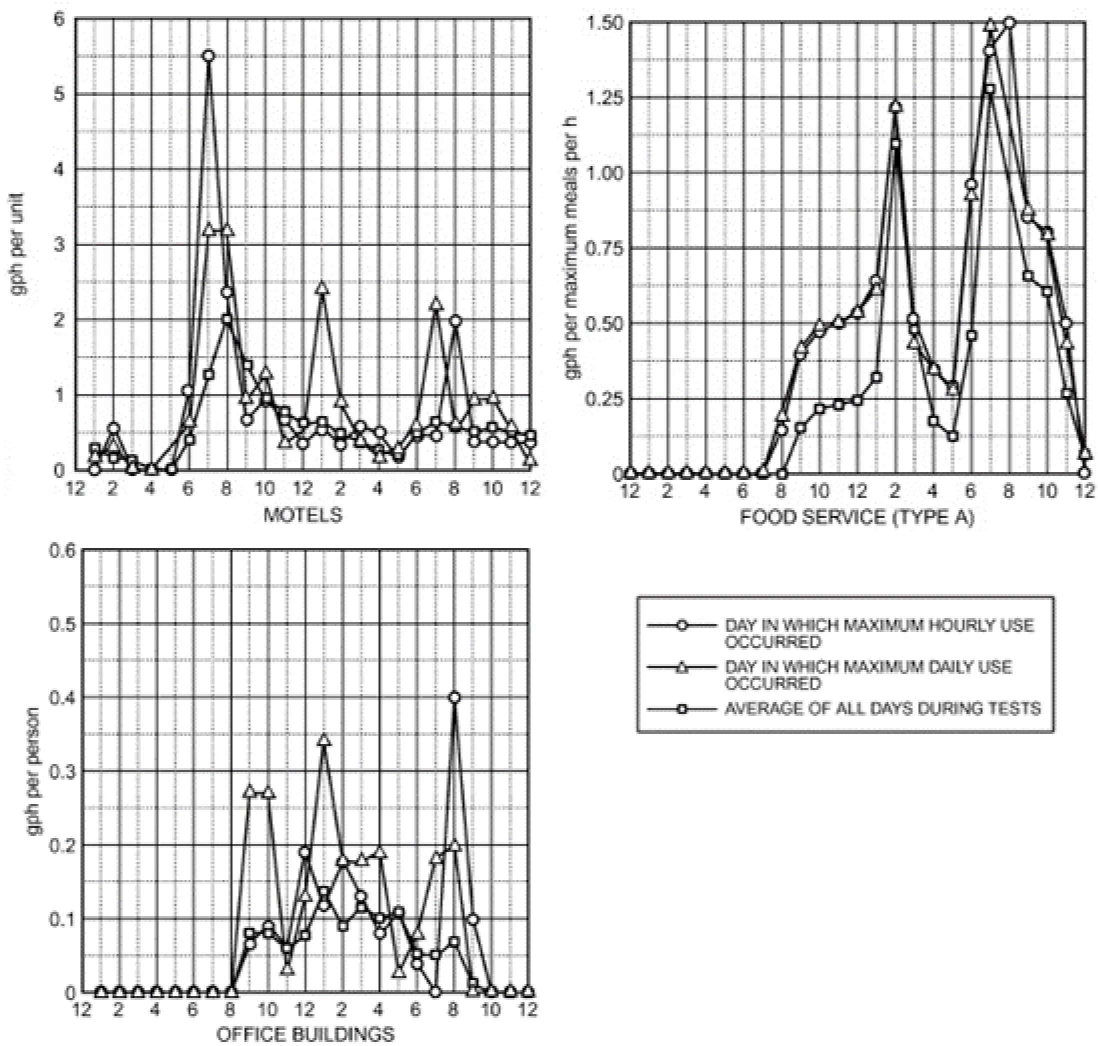
Locating detailed information regarding up-to-date, real-world hot water loads in commercial building types was extremely challenging. The 2015 ASHRAE HVAC Applications Handbook Chapter 50 Service Water Heating contains plots of hourly 24-hour hot water draw profiles for the following building types (the bolded items are of interest for this project):

- **Hotels/Motels**
- Healthcare/Institutional
- Restaurants
- **Offices**
- Retail
- **Schools**
- Warehouses
- Assemblies
- Lighting Manufacturing
- Parking Garages

These are only provided in graphical form within the Applications Handbook, with no clearly available tabular form for the datasets. Sample graphs from the Applications Handbook are shown in Figure 5. Note that the vertical axis differs from graph to graph. Understandably, residential-style applications –

apartments, hospitality, and nursing homes – have the largest gallon per hour (GPH) demands, followed by foodservice and then offices. It would be expected for most retail operations to have similar hot water demand trends as offices given typical fixture types and quantities and hot water systems sizing found in each.

Figure 5. ASHRAE Applications Handbook Hourly Flow Profiles for Various Building Types

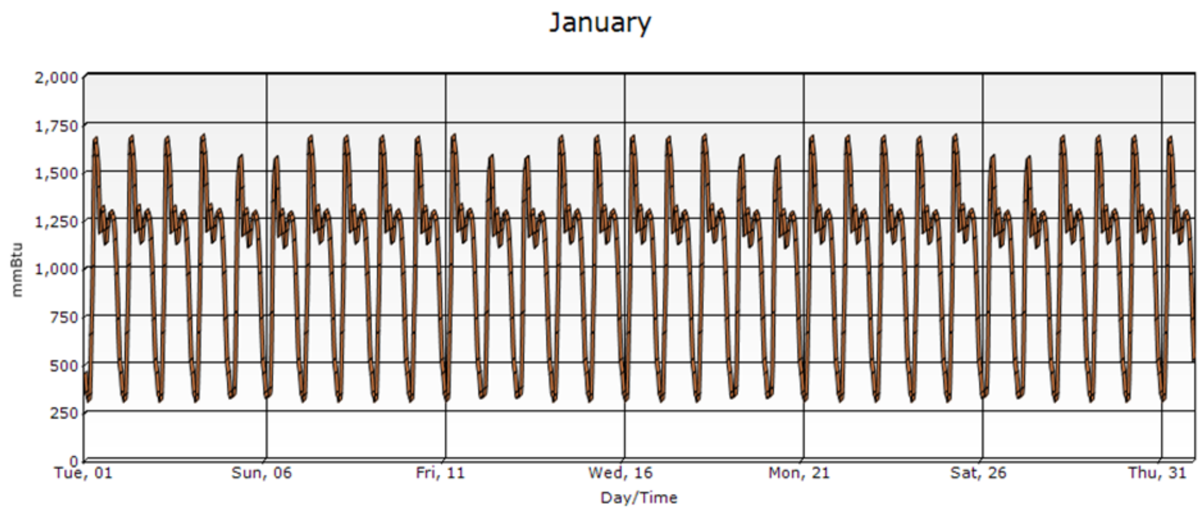


Source: ASHRAE, 2015 Applications Handbook, Service Water Heating

It appears that the ASHRAE plots date back to work documented by Werden and Spielvogel in 1969, based on the chapter references. The findings from the 1969 paper were re-documented in a 1993 report from ASHRAE Research Project (RP-600 "Comparison of Collected and Compiled Existing Data on Service Hot Water Use Patterns in Residential and Commercial Establishments"). This 1993 report does document a lot of other draw profiles and their sources, including more recent work, but the Werden and Spielvogel work dating back to the late 1960s still seems to be the primary data cited in the ASHRAE Handbook.

Select other field datasets are available, such as the 2006 California Commercial End Use Survey (CEUS), which can provide hourly profiles for a year for multiple end uses, including water heating. CEUS includes data for a variety of building types, but of special interest for this project are lodging, colleges, and retail. CEUS was a comprehensive study of the commercial building sector energy use performed by Itron in collaboration with California utilities. Figure 6 is a sample graph showing the hourly water heating loads for commercial lodging facilities in January.

Figure 6. 2006 CEUS California Lodging Water Heating Hourly Profile for January



Source: Itron, 2006 California Commercial End-Use Survey website

Methodology

Research Questions

Although on-demand hot water recirculation technology has been demonstrated in other states, it has primarily been within the multifamily sector. A field-based quantification of the technology within other commercial building types had not previously been performed in Minnesota. This project was designed to characterize demand controllers in Minnesota, specifically for hospitality and commercial buildings. This characterization will support incorporating this technology into Minnesota's Conservation Improvement Program by answering the following questions:

- What are the energy savings of the demand control system versus the baseline (24/7) system?
- What percentage of reduction in pump run time occurs in demand mode versus the baseline (24/7) scenario?
- What impact does demand control have on central domestic hot water (CDHW) generation and distribution efficiency?
- How are the energy savings affected by changes in the inlet water temperature (i.e., seasonality)?
- For a given CDHW load, how frequently is the demand control activation of the recirculation pump initiated by an actual demand versus standby loss (i.e., the loop cooling down)?
- What is the impact of the demand controller on hot water delivery time during low use periods?
- How satisfied are occupants' and building owner's with the hot water delivery?
- What was the experience for installation contractors with this technology?

Past work has verified the savings potential of demand controls for multifamily buildings in warmer climates, but there have been no studies for hospitality and commercial buildings with Minnesota's varying inlet water temperatures, and potentially increased thermal losses for circulation loops that are not in fully conditioned spaces. This study examined the commercial building types for practical applications by installing and monitoring six demand control systems.

Demand Controller

An evaluation of the currently available demand response control products was conducted to select the specific units installed in this field test. This evaluation looked at each controllers 1) fit to the field test building types, 2) demonstrations of successful installations, and 3) manufacturer experience in the commercial market. Potential controllers were identified through web searches, consultation with water heating energy experts, energy efficiency literature reviews, and emerging technology database inquiries. A total of seven possible devices were evaluated for inclusion in the project. A detailed summary of these devices is available in Appendix C.

Instrumentation

In addition to the recirculation controller, a detailed data monitoring and acquisition system was installed at each site. Figure 7 and Table 10 show the components of the basic data acquisition system installed. These instrumentation packages were modified slightly at each site to meet the specific needs of each installation. These site specific changes will be discussed in the results section. The key features of the instrumentation package were to:

1. Measure the runtime and energy use of the recirculation pump
2. Measure and compute water heater energy use
3. Measure and compute the system energy use
4. Measure water temperatures within the recirculation loop to understand occupant experience

Figure 7. Data collection and aquisition system installed at each site

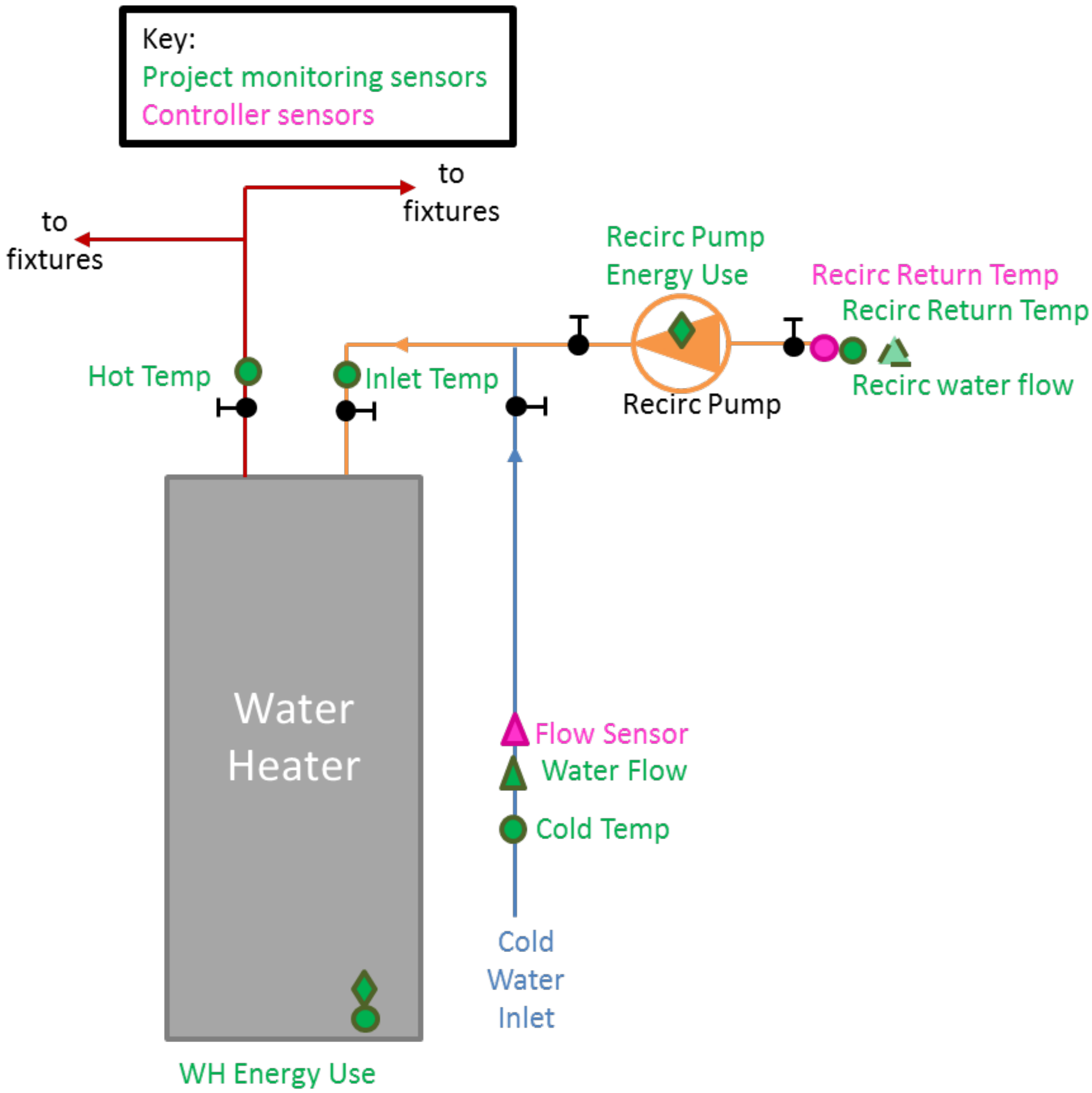


Table 10 . Data collection and aquisition system installed at each site

Measurement	Instrumentation	Location
Cold water temperature	Surface mount thermocouple	Cold water inlet
Hot water temperature	Surface mount thermocouple	Supply to loop
Return water temperature	Surface mount thermocouple	Return from loop
Hot water use	Flow meter	Cold water line into the system
Recirculation flow rate	Flow meter	In the recirc loop
Water heater energy use and runtime	Current switch or gas meter	Gas valve of DHW heating plant
Recirc pump energy use and runtime	Current switch	Circulation pump

Site Selection

This site selection process consisted of recruitment, information gathering, and selection phases.

Commercial and hotel properties were recruited primarily from contacts with the project team. These contacts were acquired as a result of conducting a range of research projects and consulting work in these building sectors. Buildings were targeted based on their fit for demand based controller application. These characteristics included hot water uses distributed throughout the building, centralized DHW systems, and recirculation loops.

Once buildings were recruited site visits were conducted to collect information on each building including the overall building size and use, the hot water heating and distribution system equipment and design, the types and locations of end use fixtures, and baseline system operating parameters. The initial plan called for a short data collection period at 10 buildings to characterize the recirculation pump runtime, and water temperatures within the DHW system.

Based on the building and system information and data collected at each potential building a subset of six buildings were targets for the full field evaluation. These six sites included two middle schools, one capitol administration building, and three hotels.

Monitoring

The six field sites selected for the project had a demand controller and data monitoring equipment installed. At a minimum, the monitoring package at each field site included three types of sensors. A water flow meter was installed to measure the hot water usage at the site. Power and runtime meters were installed to measure the energy use of the recirculation pump and water heater. The last type of sensor installed was thermocouples to measure water temperatures. The inlet and outlet temperatures of the water heater and recirculation return temperature were also measured. This data was collected at a one second time interval to allow for individual event analysis. An alternating mode test was then conducted for at least 10 months. The controller was alternated between the on and off mode to capture baseline and controlled data in all seasons.

Analysis

Data analysis focused on an evaluation of the savings potential of demand controllers in a range of commercial applications. The alternating mode test design was used to ensure that data was collected under the full range of operating conditions in both controlled and baseline modes of operation. This methodology allowed the project team to consider not only average performance, but also the impact of seasonality on performance. A multi-step process was used to determine the annual performance at each site.

1. High resolution interval data was collected at each site.
2. Data was aggregated to look at daily and weekly performance
3. Daily and weekly data was used to determine the energy delivered to each building as hot water by the system. This load data was also assessed for seasonal impacts due to outdoor temperatures, ambient conditions, and inlet water temperature
4. The measured data was used to characterized the relationship between energy delivered (load) and energy consumption of each system for both the baseline and on-demand controller periods.
5. Data and relationships from the previous steps were used to calculate the annual performance of each system

In addition to the annual energy savings, several secondary impacts were also assessed and analyzed to understand the impact of the controller on the system and building performance. Water temperatures and flow rates were used to understand the impact on delivered water temperature and the potential impact on space conditioning loads due to heat loses from the water heating system.

Interviews

As with any new technology successful implementation will require-buy in from important stakeholders. For a controller, like the one being characterized here, a positive relationship with both contractors and installers as well as owners and operators is necessary. The project planned to conduct two series of informal interviews, one focused on the installers, the other on the building owners or operators. The contractor interviews tried to understand the ease of installation and commissioning of the device, while the owner and operator interviews focused on the operation and level of satisfaction with the device.

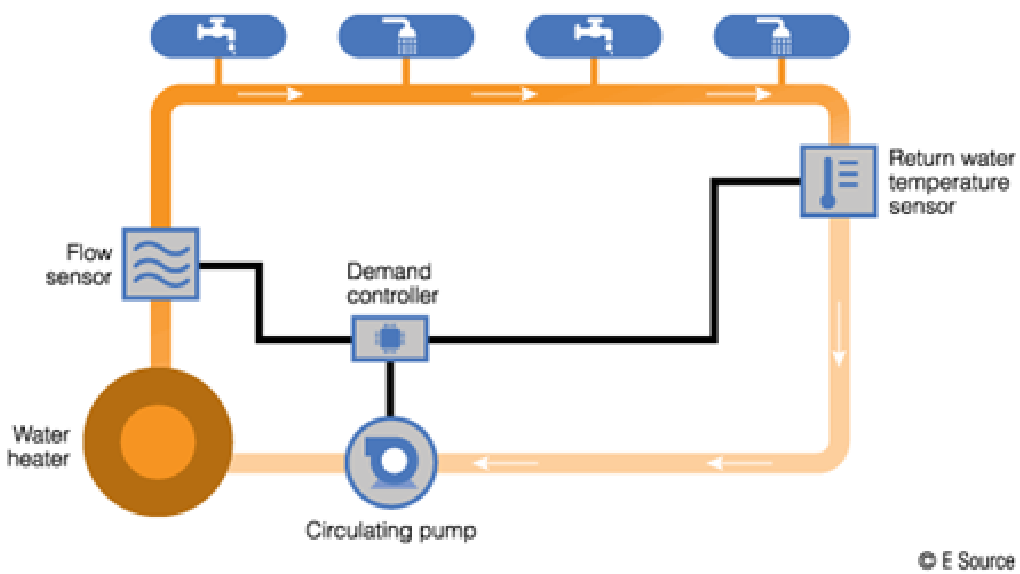
Results

Demand Controller

The demand response controllers that were selected and installed in this project were supplied by Enovative Kontrol Systems. These controllers were selected based on their demonstrated success in past field evaluations with Gas Technology Institute (GTI) and the overall fit between the controller design and the desired outcomes of this project. A total of seven possible devices were evaluated for inclusion in the project. A summary of these devices is available in Appendix C. Enovative was the most robust and experienced manufacturer. The six field sites selected for the project had a demand controller and data monitoring equipment installed.

Figure 8 shows the demand controller components and their typical installation locations. This controller consists of a flow sensor, a surface mounted water temperature sensor, and the control box. The flow and temperature sensors communicate with the controller. Using data from the sensors, the control algorithm relay a signal to the controller about when to run the recirculation pump.

Figure 8 . Demand control system for central recirculation systems



Site Selection

After soliciting a range of hospitality and commercial sites in Minnesota and collecting runtime data at 14 buildings six sites were selected for this project. These six sites included two middle schools, one capitol administration building, and three hotels. These sites were selected to characterize a range of the possible applications for this controller. Table 11 shows that range of sites that were installed. These sites include numerous building types, heat sources, and recirculation loop uses. The specific details of systems and setup at each site are discussed in Case Study section below.

Table 11. Site characteristics

Site ID	Type	Heat Source	WH specs	Circulation Pump	Pump Use	Recirc Loop use
Com_Ed_01	Middle School	Indirect Steam	District steam	Grundfos UPS15-55SFC - On HI speed	87 W	Class & bathrooms
Com_Ed_02	Middle School Pool Facility	Indirect Dedicated Boiler	Lochinvar Cond. Boiler (AWH1000)	Bell & Gossett PL-45B	400 W	Pool/Gym Locker Rooms
Com_03	Office Building	Electric Water Heater	AO Smith 9000W 120 Gal 0.41% standby loss	Taco 1600 Series	390 W	Office & bathrooms
Hosp_01	Chain hotel - Standard rooms	Indirect Dedicated Boilers	Cleaver Brooks non-Cond Boiler (M4W-2500)	Bell and Gossett Series 60 Pump	190 W	Hotel Rooms
Hosp_02	Chain hotel - Mostly Suites	Three Condensing Gas Water Heaters	Bradford White (EF100T399E3NA2)	Taco 1600 series	370 W	Hotel Rooms
Hosp_03	Budget hotel	Three non-Condensing Gas Water Heaters	Rheem (G91-200-1)	Grundfos UPS15-55SFC	100 W	Hotel Rooms

Monitoring

Although the original intent was to monitor the sites in a week-on/week-off fashion – namely, that they would be operating in baseline 24/7 mode for a week, and then be switched to on-demand operation for a week – this was not practicable in the field. Alternating the operational mode required manual adjustment of the controller at each site. Difficulty in coordination of on-site personal and project staff, made switching the mode weekly impractical. As a result, longer periods were used for each mode at each site. Due to differences in recruitment times and installation schedules, each site was monitored for a different length of time. The total monitoring periods for each are summarized in Table 12 and Table 13.

Table 12. Site Installation and Removal or Retention Details

Site ID	Equipment Installed	Interval Data Time (Seconds)	Start of Data Collection	End of Data Collection	Total Monitoring Length (months)
Com_Ed_01	4/7/16	15	4/8/16	4/1/17	12
Com_Ed_02	4/8/16	15	6/24/16	4/11/17	8
Com_03	12/13/16	1	12/20/16	6/18/17	6
Hosp_01	4/18/16	15	8/1/16	12/7/16	4
Hosp_02	7/27/16	1	9/22/16	5/16/17	7
Hosp_03	3/2/17	1	3/3/17	6/18/17	3

Table 13. Data Monitoring and Collection Details in Baseline and On-Demand Mode

	BASELINE			ON-DEMAND		
Site ID	Total Number of Days Data Collected	Number of Days with Missing/ Invalid Data	Percent Logged	Total Number of Days Data Collected	Number of Days with Missing/ Invalid Data	Percent Logged
Com_Ed_01	-	-	-	-	-	-
Com_Ed_02	90	0	100%	191	0	100%
Com_03	119	10	92%	45	24	47%
Hosp_01	128	0	100%	0	0	0%
Hosp_02	215	66	69%	20	0	100%
Hosp_03	37	2	95%	50	15	70%

Additionally, HOSP_01 had a number of concerns about operating in on-demand mode and ultimately requested the removal of the on-demand equipment before any on-demand data was collected at the site. Therefore, only baseline 24/7 mode operation was tracked at that site. While this adds to the team's knowledge about baseline usage patterns, the site was unable to provide any useful comparisons to address the key research questions outlined by the project.

Once the controller was activated field staff performed and verified that the controller passed a three-step commissioning and operation check (Table 14).

Table 14. Controller commissioning process

Step	Process
1.	Enable the controller
2.	Once the controller is enabled, wait for a period with no demand. Confirm the controller has shut off the recirculation pump[4].
3.	Once the pump has turned off, remove the temperature sensor from the recirculation return exposing it to ambient air temperature. When a demand occurs on the system, confirm that the recirculation pump has been activated.

Instrumentation plans for each of the sites are laid out in Appendix A.

Interviews

Installer Interviews

The demand based controller was relatively new to the Midwestern market at the start of the field installation phase of this project. The manufacturer did not have a contractor or installer relationship developed in Minnesota. There were no installers with significant experience with this technology. A single installer was used for all of the sites in the field characterization. The installer was interviewed to determine the ease of installation and likelihood of working with this device in the future.

Prior to any installations the installer, who was a licensed plumber and had a lot of prior experience in commercial and hotel properties, was confident that the installation process described in the manufacturer's materials would not require any skills or knowledge beyond what would be expected of a professional plumber. However, the installer wanted to be able to inspect each site before installation, as deviations from the typical install could provide additional install steps and complexities.

After all six installations were complete, the installer commented that typical installations would be straight forward and could be completed in a two to three hour time frame. However, the contractor mentioned that more complex and detailed installations were required for many sites where the plumbing layouts did not follow the typical scenario. In general, the technical requirements of the installation can be easily and quickly performed by any contractor, but understanding the implications of each component and installation of more complex systems takes a greater understanding of the controller operation and the buildings hot water system, including knowledge from outside the mechanical room.

[4] This step assumes the controller was installed on a system previously running with continuous circulation, so this process takes place when the return water temperature is greater than the controller shut off point.

Owner or Operator Feedback

Feedback was collected from each of the owners and/or operators of the field sites. At the start of the project, each site was intrigued by the idea or reducing hot water energy use, while maintaining system performance and occupant comfort. In the hospitality sites, the most significant concern was occupant comfort. As hotel business is typically dependent on repeat customers. A single dissatisfied customer is unacceptable. This concern was present in commercial buildings, but to a lesser degree. In commercial properties, customer relationships are longer term and dissatisfaction over a single occurrence is not desired, but is more tolerable.

At the completion of the project only two of the six sites opted to keep the control device. One of the three hotel properties, Hosp_3, kept the controller. At that site, the hotel never received complaints and energy savings were significant. Despite having three storage water heaters, the plumbing design on this site was very typical and the installation went smoothly. The operators and owners had no complaints. At the other two hotel properties, owners and operators decided to remove the controller. Further details will be provided in the following case studies, but each of these installations were more complex and required on-site engineering. A second hotel site, Hosp_1, had a change of owner during the project and the installation and set-up process was never completed. The second of these sites, Hosp_2, had a couple of water temperature complaints and was unable to run the controller for the full monitoring period. The data collected in the project showed the controller was working as designed, but return water temperatures were remaining warm enough to prevent the recirculation pump from activating. It was expected this issue was caused by unintended flows (from cross-over issues) or inconsistent water temperatures within the recirculation loop (unbalanced zones). However, the operator preferred to just resort to what was working prior to the project as any customer dissatisfaction was unacceptable.

The commercial properties had operation similar to the hospitality sites; one of the three installed controllers remained operational at completion of the project (Com_ed_02). After the installation and set-up, the building operators at this building did not think about the controller again until the completion of the project. It operated as expected and did not impact occupants' experience. Com_ed_01 had difficulties integrating the system with the Building Automation System operating at the site. The controller continually tripped sensors and alarms that assumed the recirculation pump would be operational 24/7. The onsite staff was unable to fully adjust these alarms to prevent continual alerting. They continued to alarm throughout the project. Com_3 was on the fence about keeping the controller. They did not receive occupant complaints, but the operations staff had several buildings to manage and the installation of the controller took a couple of commissioning visits (see Case Study). This experience soured the owner, and he wanted to remove the controller himself.

Case Studies

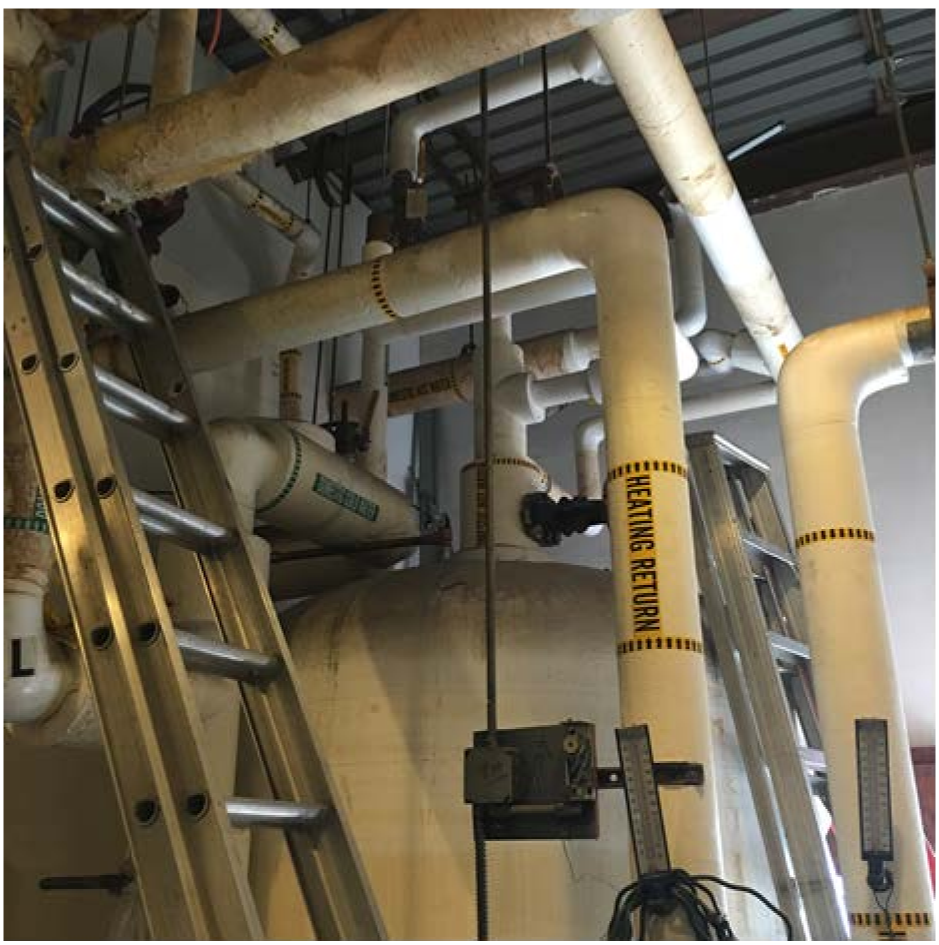
The initial characterization work conducted (Phase I) showed that central DHW systems in existing commercial and hospitality buildings have a wide variety of designs. This observation guided the site selection process to target a variety of systems. Therefore, detailed monitoring was conducted at six sites. These sites included three hospitality properties, two educational buildings, and an office building. The unique nature of each of these systems changed the installation, monitoring, and logistical approaches at each site. Because of these differences the analysis methodology differed for each site. A case study will be presented for each of these sites with a summary of the findings to follow.

Hospitality Site 1 – Large Chain Hotel

The first hospitality site, Hosp_01, was a large chain hotel located in a commercial plaza just off a major interstate. The commercial plaza also contains a number of office buildings and is across the street from a number of adjacent commercial developments. The 5-story, 252 guest room, hotel building also has over 10,000 square feet of event space, which can accommodate up to 500 conference or banquet guests. They also have a pool, fitness center, business center, restaurant, bar, meeting center, and laundry facilities.

Installation and Instrumentation

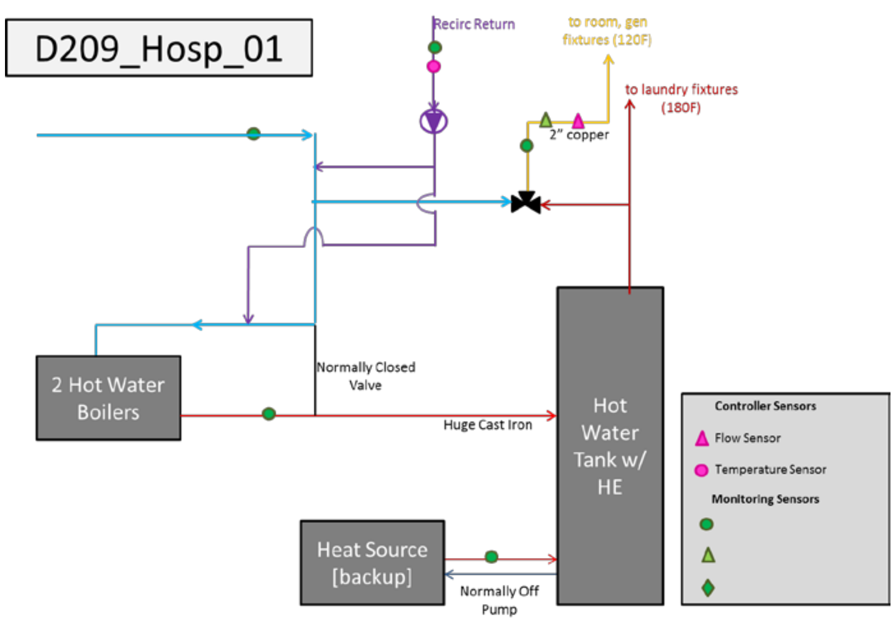
Figure 9. Image of the large indirect water tank at Hosp_1



The building had a complicated hot water system (Figure 9), consisting of one massive storage tank, two recirculating distribution loops, and three plumbing loops for heating the tank. The primary heat source for the system were two dedicated commercial boilers, set up as a primary and back-up relationship. The third potential heat source was a further redundancy that was not actively connected to the system, had no heating plant connected, and was valved off. Most of this system had been installed for many years and predated all current operations personnel. The controller installation and monitoring project focused on the guest room circulation loop which used copper piping and supplied all 252 guest rooms.

There were many challenges with the installation at Hosp_1, both technical and practical. This DHW system was very complex, with multiple redundant heat sources, multiple distribution loops, as well as several desired operating conditions all interacting through the same very old tank. This complexity made the controller sensor installation difficult. Additionally, the building operators had no documentation and did not have any information about design of the system. All we know of the DHW system, distribution loops, controls, and operating parameters had to be determined or estimated from on-site inspection of the mechanical room without access to plans, a knowledgeable building operator or access to all the plumbing loops the locations of end uses, balancing values, and piping locations had to be estimated. This led to difficulties in commissioning and troubleshooting the controller operation. Figure 10 shows the system layout and the controller installation locations as determined by the project team, building operators, and control manufacturer. The installation was complicated further when the project field personnel discovered that the building operations personnel were unsupportive of the installation, despite the support of the building management.

Figure 10. Diagram of the central DHW system at Hosp_01



Operation

Following installation in April 2016, the on-demand controller did not appear to be operating correctly and the system was only operating in baseline 24/7 mode. When operating in the control mode, the controller would interrupt the circulation pump and stop system circulation. In normal operation the recirculation return would then decrease as the loop cooled, eventually activating the controller and circulation pump. However, the return water temperature remained warmer than expected, which impacted when the recirculation pump would reactivate. Project staff made a number of site visits over the summer to determine the cause for this. One possible explanation of this was hot water flow occurring is an unexpected direction when the pump was deactivated. One commissioning site visit that was made included installing additional check valves to enable correct operation. Unfortunately, the building operator continued to be unsupportive of the work and site access issues became a chronic problem, which made commissioning the control and verifying performance impossible. Through the fall and early winter the host site was largely unresponsive to requests to visit the site and the system was operating only in baseline 24/7 mode. The property had a change in management and the host site requested removal of all project related equipment. At the end of January 2017, with equipment removal complete, the site suspended participation in the project. The project team was unable to determine the ultimate cause of the operational issues. The controller was never fully installed and commissioned. Unfortunately, this means there is no on-demand data available for comparison.

During the final site visits the controller was able to pass the commissioning process, but within a short period of time the controller was deactivated. Site access, operator hesitance to run the controller and work with project staff prevented the research team from understanding the controller performance at this site.

With the limited data that was collected during the controller active period, it was noted that the recirculation return water temperature never dropped below 108 ^{o}F, even during periods where the system was in stand-by and the controller had deactivated the recirculation pump. There were at least two possible explanations. First, when the recirculation pump in the system was turned off, backflow through the pump and into the recirculation loop in the opposite direction kept the controller temperature sensor artificially high. A contractor was hired to inspect the check values in the system and install additional check values. After assessing that the check values had not failed and installing additional valves the return temperature remained the same. This meant the counter flow was unlikely, but lack of access prevented a complete understanding. The second potential explanation was additional undetermined flow in the recirculation return line. This property has had many operators in its history and any plumbing schematics that were created were no longer available. Additionally, much of the plumbing system was outside the mechanical rooms and in areas with limited access. The building operators assumed that the laundry room distribution system was not part of the recirculation system and, instead, was only supplied from the large indirect tank. However, the project team did not have the access to verify the plumbing configuration and the reason for the high-return water temperatures in idle mode was undetermined.

Analysis and Results

The results for baseline operation are summarized in Table 15. Using the baseline data and the expected savings, we can estimate the annual savings had the demand controller been commissioned and operational at this site. A 14% water heater energy reduction would have saved 1,880 therms per year of natural gas. An 87% reduction in recirculation pump runtime would have resulted in 1,445 kWh/year saved in pump energy.

Table 15. Summary of On-Demand and Baseline Results HOSP_01

Description	On-Demand Control Mode	Baseline Mode
Hot water use, gallon/day	N/A	4,313
Energy Delivered (Qout), therm/day	N/A	19.7
WH Energy Use (Qin), therm/day	N/A	35.9
Annual WH Use, therms [a]	11,213	13,094
Annual WH Cost, $ [a b]	$10,652	$12,439
Water Heater Savings [a]	14.4%	N/A
Runtime Recirculation Pump,hours/day	N/A	24.0
Pump Electric Power, W	190	190
Pump Energy use, kWh/day	N/A	4.6
Annual Pump Use, kWh	220*	1,664
Annual Pump Cost, $ [b]	$29*	$216
Pump Savings	86.8%[a]	N/A
Total Annual System Cost	N/A	$12,655
Total Savings [a b]	$1,974	N/A
Total Percent Savings [a]	15.6%	N/A
Average Hot Water Temperature (degrees Fahrenheit)	N/A	137
Average Recirculation Loop Temperature (degrees Fahrenheit)	N/A	125

a. *On-demand performance was estimated based on the project average percentages saved for thermal (14.4%) and pump energy (86.8%). These savings were not measured for this site.

b. The operational costs are calculated using average residential pricing in 2017 for natural gas and electricity from Energy Information Administration. Average annual costs are $0.13/kWh for electricity and $0.95/therm for natural gas (US EIA 2014).

Hospitality Site 2 – Mid-sized Chain Hotel

The Hosp_2 building is located immediately off of interstate 35-West. It is a mid-sized chain extended-stay hotel. Commercial development lies just to the north and south of the building. It's a 5-story building surrounded by an ample lawn buffer. As an extended-stay hotel, each of the 124 guest rooms is a suite complete with separate living and sleeping areas and a fully-equipped kitchen. Laundry service is also provided, along with a pool, fitness center, and meeting rooms.

Installation and Instrumentation

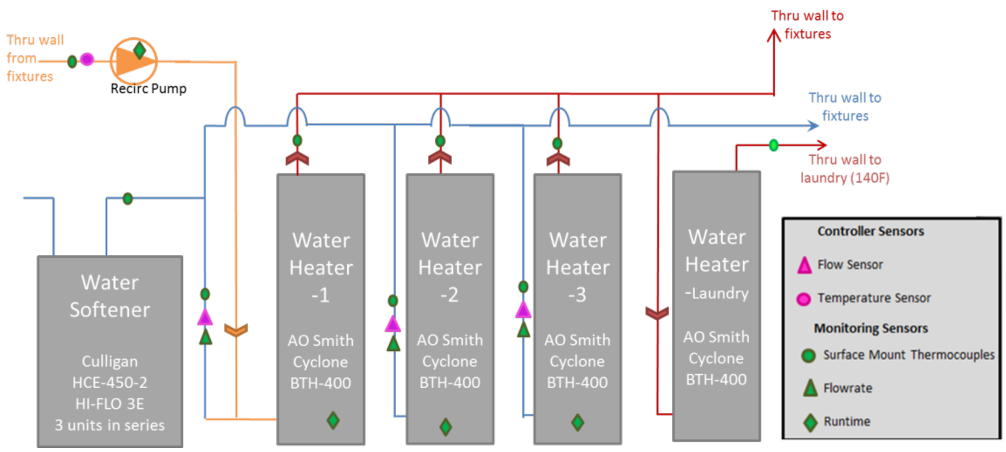
Hosp_2 has a central DHW loop, prior to the project the recirculating distribution loop ran continuously 24 hours a day. The hot water load for the building is heated by three condensing storage water heaters (Figure 11). The water heaters provide heat to a distribution loop that supplies hot water to the laundry and guest rooms. The laundry room was treated the same as any other fixture of the distribution systems, but it had an additional booster heater in-line to deliver water at a hotter temperature for laundry use.

Figure 11. Central DHW area of the mechanical room at Hosp_2

Figure 12 shows the plumbing layout for Hosp_2 and the location of the controller and data monitoring sensors. This site had three large water softening units installed on the inlet to the water heaters.

Because of the small distances between these water softeners, the water heaters and the location where the cold water pipe enters the mechanical room the flow sensor was not able to be installed on the single inlet pipe. Instead three sensors were installed at the inlet to each individual water heater. The signals for each of the flow sensors were added together; if any of the three sensors indicated flow the controller would know there was a hot water demand.

Figure 12. Plumbing layout and instrumentation and controller locations for Hosp_2



Operation

The demand controller had some operation issues at Hosp_2. Some of these issues were logistical and others were performance based. These issues combined to limit the operational days for the controller. For the 234 monitored days at Hosp_2, only 20 or 8% of the days were in the controlled mode. Therefore, savings and performance estimates for the controller were based on limited runtime information. Fortunately, experience and analysis at the other sites in this project led the project staff to have full confidence in the estimates at this site.

The initial control mode operation was active for 20 days before being changed to a baseline period (9/22/16 to 10/11/2016). After the baseline period (10/12/2016 to 11/15/2016, project staff re-activated the controller for the second monitored period (which started 11/16/2016). Within a few days of activating the controller the on-going data checks revealed that the system had been returned to baseline mode (continuous recirculation). Project staff reactivated the control and performed the operational check on 1/17/2017. Despite passing the operational check at each change over (on 11/17/16, 1/16/17, 2/12/17, and 3/8/17) it was later learned that hotel staff had disabled the controller within 2 days of the start of each controlled period. Upon further discussion with the hotel staff, it was learned that the hotel received two complaints from the top two floors of the property on the first night of the 2nd operation period (11/17/2016). These complaints caused the operations staff to bypass the controller.

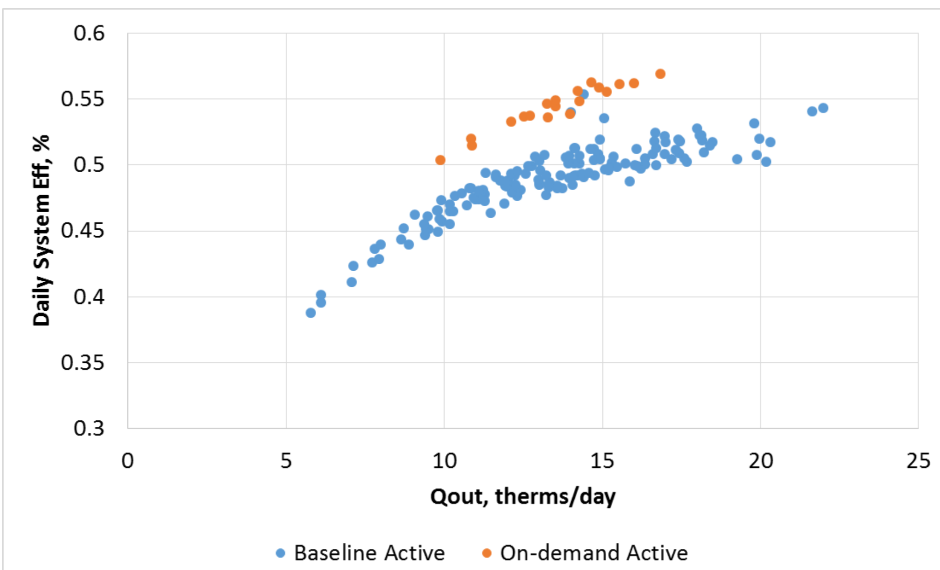
Further review of the system performance data, the two complaint reports, and the limited information about the plumbing system, led the project staff and the manufacturing partner to suspect there were existing system operations issues that were being exacerbated by the control system. Continuous recirculation can overcome underlying issues in many CDHW systems. For example, hot water circulated continuously masks problems in balancing the distribution system to different parts or floors of a building. It can also hide significant cross over flows between the hot and cold loops, concealing significant energy waste and loss. These problems would explain how the return water temperature can be maintained at 110 ^{o}F during controlled operation, but some parts of the building would not be able to get hot water. Unfortunately, follow-up testing to confirm this hypothesis was not possible at this building.

The operation of the controller at this site highlight one additional lesson. Hospitality properties were expected to be a good fit for this technology due to the similarities in expected hot water load and system designs with multi-family buildings, where this controller has worked successfully (Bender and Kosar 2014; Ayala and Zobrist 2012; Benningfield Group 2009). Hosp_2 highlighted key differences in these applications. Hospitality buildings have a significant incentive to delivery occupant comfort at all times. A hotel guest that receives unacceptable hot water performance, even once, is unlikely to return to that hotel. Because of this, hotel staff were quick to disable and bypass the control.

Analysis and Results

Despite the operation difficulties, the 20-day period of consecutive controller operation (without issues or interruption at the start of the project) allowed for a full analysis.

Figure 13. Daily system efficiency at Hosp_2

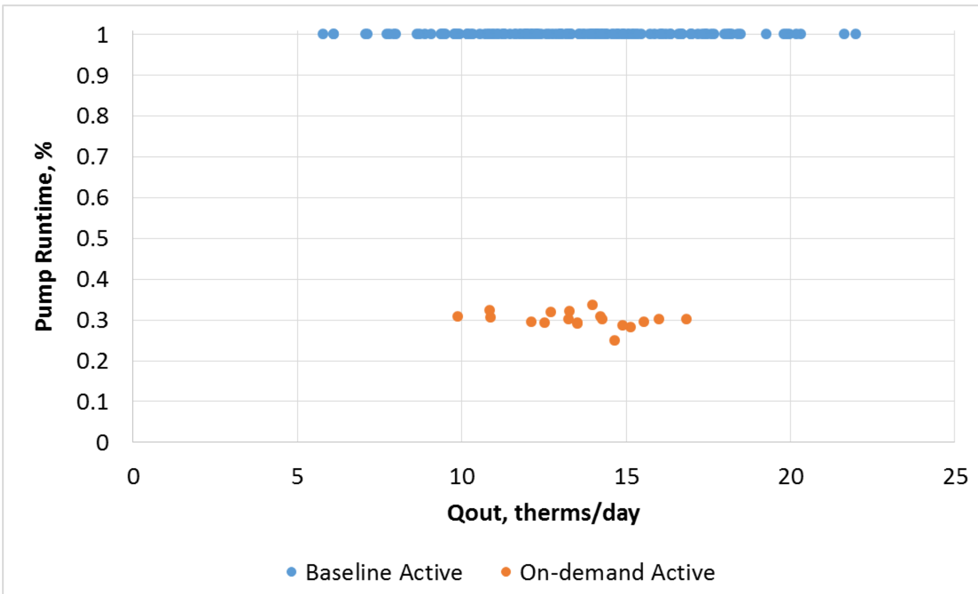


Field instrumentation was used to calculate and compare the energy delivered by the system as hot water, to the energy consumed by the system in natural gas and electricity. The energy delivered to the system, Qout, was calculated from the measurements of water flow into the water heater, the system inlet water temperature, and the hot water temperature delivered to the distribution system. This measurement of efficiency accounts for the heat loses due to recirculation and the storage loses from the water heater tank, but does not account for distribution loses on water delivered to the tap. Figure

13 shows the system efficiency for both demand controlled and baseline modes. This plot accounts for the energy delivered to the system and the water heater energy consumption. The figure shows that during the controlled mode the energy efficiency of the system was increased compared to the baseline efficiency during continuous recirculation.

In addition to the water heater energy consumption savings, shutting off the pump during the demand controlled mode reduced the pump energy use. Figure 14 shows the runtime of the constant speed recirculation pump in this building. Hosp_2 shows a 70% reduction in pump runtime. With the 400 Watt recirculation pump at this site the controller would save 7.2 kWh per day.

Figure 14. Electric Use at Hosp_2



In order to estimate the annual savings, the seasonal effects on hot water loads were determined at each site. Figure 15 shows how the hot water energy usage at Hosp_2 was impacted by the inlet water temperature. In single-family residential DHW applications there are typically strong seasonal impacts (Bohac et al. 2010; Schoenbauer 2015). These seasonal impacts are due to the extra energy necessary to heat colder water in the winter and the need to mix a higher fraction of hot water in mixed draws, such as showers. The figure shows a statistically insignificant impact from the seasonality of the inlet water temperature. This is likely due to the increased volume of water inside the conditioned space. For example, there is a large volume of cold water piping between the cold water inlet and the taps inside the unit. For shower draw in this building the cold water temperature would be closer to the ambient temperature, through which the pipe passes, than in a single-family system when the pipe lengths and volumes are much smaller.

Figure 15. Seasonal impacts of inlet water temperature on the DHW load at Hosp_2

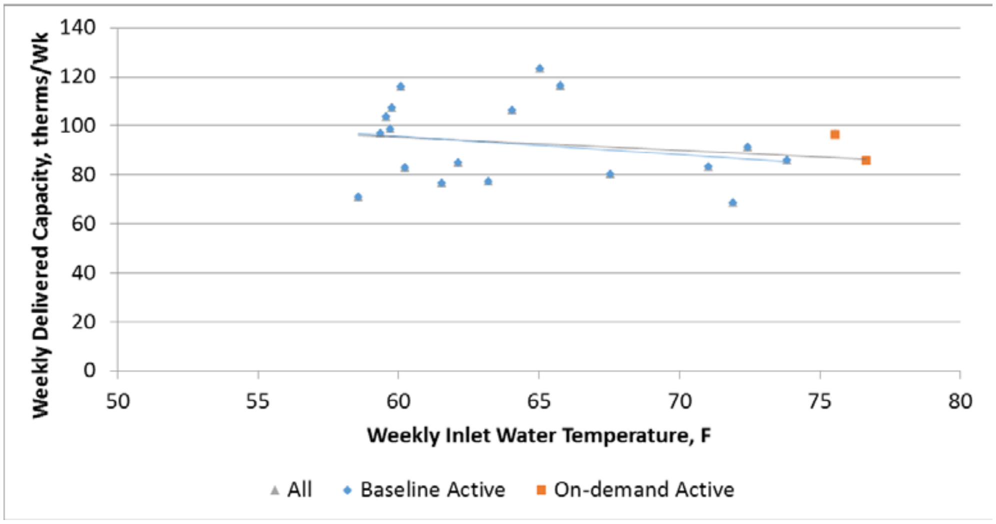


Table 16. Summary of On-Demand and Baseline Results at HOSP_02

Description	On-Demand Control Mode	Baseline Mode
Hot water use, gallon/day	3,210	3,210
Energy Delivered (Qout), therm/day	13.5	13.5
WH Energy Use (Qin), therm/day	24.6	27.3
Annual WH Use, therms	8,979	9,965
Annual WH Cost, $	$8,530	$9,466
Water Heater Savings	9.9%	N/A
Runtime Recirculation Pump, hours/day	7.2	24.0
Pump Electric Power, W	420	420
Pump Energy use, kWh/day	3.0	10.1
Annual Pump Use, kWh	1,104	3,679
Annual Pump Cost, $ b	$143	$478
Pump Savings	70%	N/A
Total Annual System Cost [a]	$8,674	$9,945
Total Savings	$1,271	N/A
Total Percent Savings	12.8%	N/A

a. The operational costs are calculated using average residential pricing in 2017 for natural gas and electricity from Energy Information Administration. Average annual costs are $0.13/kWh for electricity and $0.95/therm for natural gas (US EIA 2014).

With limited impact on seasonality the hot water use at average weather conditions was used for analysis. This usage was 3,210 gallons per day of hot water, which is a hot water load of 135 MMBtu per day. Table 16 shows the annual usage and savings results. A full year of demand control at Hosp_2 would yield 9.9% water heater energy savings, and a 70% reduction in pump energy. This site would achieve an annual DHW operation savings of $1,271.

Hospitality Site 3 – Mid-sized Budget Hotel

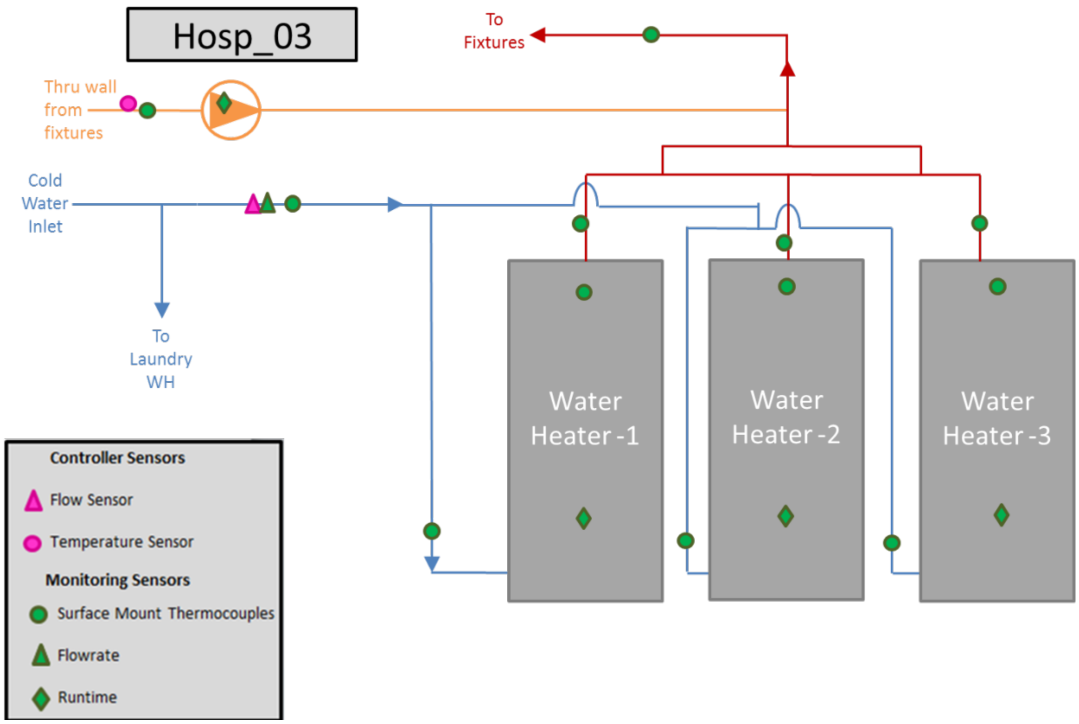
The third hospitality site, Hosp_3, is a mid-sized budget hotel chain. The building is a 3-story hotel, with 60 guest rooms and amenities including a pool, fitness center, laundry, and buffet breakfast. It is located within a larger commercial center, just north of the 694 freeway. The monitored recirculation loop serves the entire hotel and is built of copper pipe.

Installation and Instrumentation

The central DHW system at Hosp_3 was typical and a simple design for this building type. The system used three gas water heaters to supply heat to a single recirculation loop (Figure 16). The control sensors (both flow and temperature) were installed in the manufacturer's preferred locations (Figure 17).

Figure 16. Water heating area of the mechanical room at Hosp_3

Figure 17. Controller sensor and instrumentation locations at Hosp_3



Hosp_3 followed the standard instrumentation and monitoring methodology. There were additional sensors added because there were multiple water heaters. The combined inlet and outlet water temperatures were used for the analysis, but each water heater was also measured independently. Runtime sensors were used on the burner valve of each water heater. Temperature sensors placed in the flues were installed as a back-up water heater runtime measurement, but were never needed. Figure 17 shows the system layout and the location of each sensor.

Operation

Recirculation pump runtime was reduced significantly in on-demand mode. In baseline operation pumps ran continuously 24 hours per day, in on-demand operation the pump only ran about 7% of the time (or an hour and 40 minutes per day). With the reduced pump runtime the water temperature in the distribution loop was significantly cooler in controlled mode. Figure 18 shows the recirculation loop temperatures for a typical day in each mode. Lower distribution temperatures result in lower thermal loses from the loop to ambient conditions. Heat losses from the distribution system were 25% lower when the system was operating in on-demand mode (Figure 19).

Figure 18. HOSP_03 Recirculating Loops Temperature

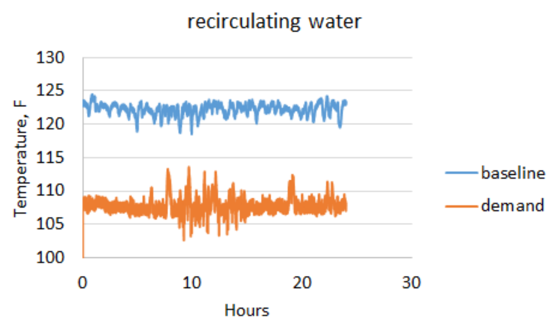
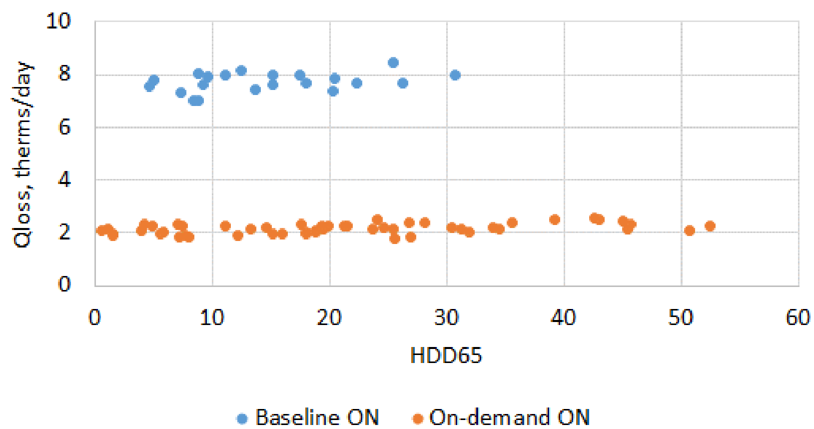


Figure 19. HOSP_03 Heating Distribution Losses by Operating Mode

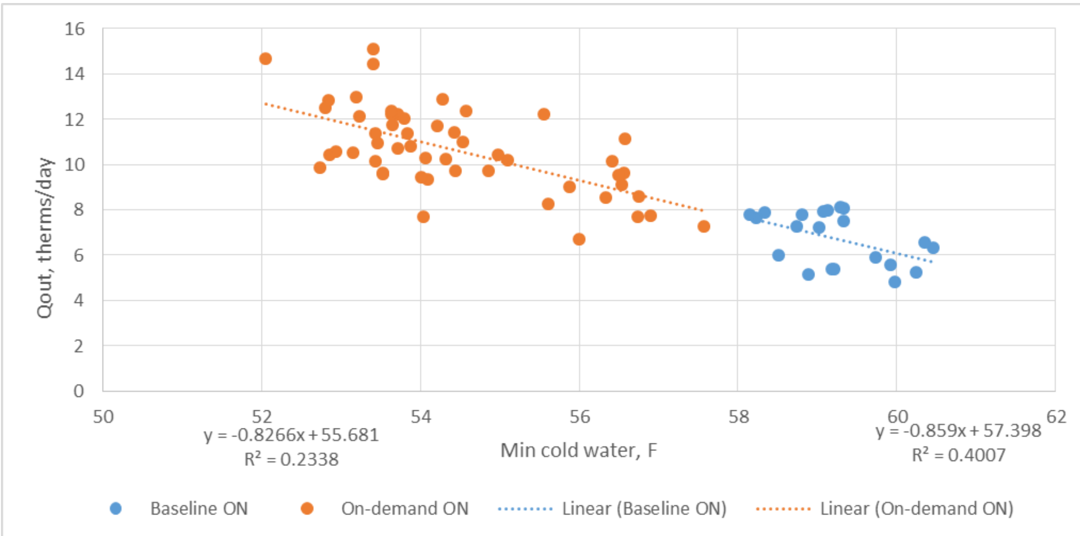


To better understand whether there was a lag time in water heating while the system was operating in on-demand mode, the team compared a 24-hour period with similar daily water usage totals. No lag time in water heating was seen when the system was operating in on-demand mode as compared to baseline mode.

Analysis and Results

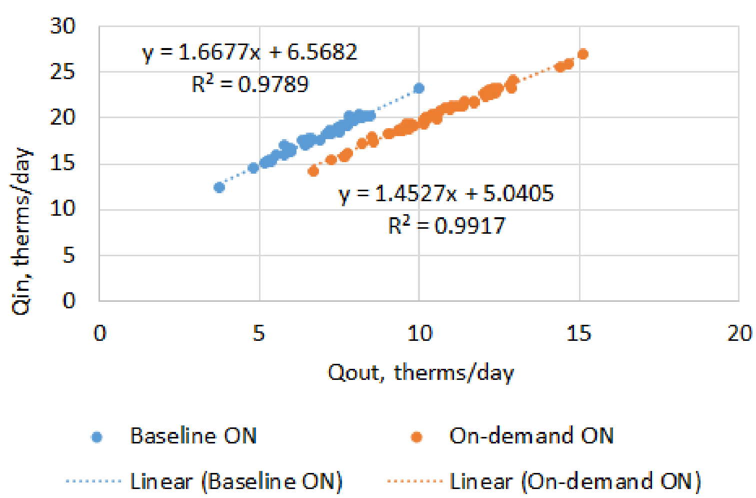
The hot water load at Hosp_3 had a significant dependence on the inlet water temperature (Figure 20). At 52^{o}F during the coldest season the DHW load was about 13 therms per day. In the summer, at 60 ^{o}F the load was only 6 therms per day. There was no statistical difference between the two modes of operation and there for a single seasonality curve was used.

Figure 20 . Seasonality of the DHW load in each mode of operation for Hosp_3



The operational mode did have a significant impact on energy use at Hosp_3. Figure 21 shows the measured relationship between energy input and output at this site. The on demand mode used significantly less energy to deliver the same DHW load.

Figure 21. HOSP_03 Energy Delivered vs Energy Used by Operating Mode



The seasonality relationship (Figure 20) and system performance relationship (Figure 21) were used to calculate the annual energy performance (Table 17). At Hosp_3 the demand controller saved 15.9% of the water heater energy use and 93% of the electrical pump energy. These energy savings resulted in a $1,320 per year savings.

Table 17. Summary of On-Demand and Baseline Results at HOSP_03

Description	On-Demand Control Mode	Baseline Mode
Hot water use, gallon/day	1,822	1,822
Energy Delivered (Qout), therm/day	9.6	9.6
WH Energy Use (Qin), therm/day	18.9	22.5
Annual WH Use, therms	6,907	8,211
Annual WH Cost, $	$6,561	$7,800
Water Heater Savings	15.9%	N/A
Runtime Recirculation Pump, hours/day	1.7	24.0
Pump Electric Power, W	77	77
Pump Energy use, kWh/day	0.1	1.8
Annual Pump Use, kWh	47	675
Annual Pump Cost, $	$6	$88
Pump Savings	93.0%	N/A
Total Annual System Cost[a]	$6,568	$7,888
Total Savings	$1,320	N/A
Total Percent Savings	16.7%	N/A
Average Hot Water Temperature (degrees Fahrenheit)	131.2	126.3
Average Recirculation Loop Temperature (degrees Fahrenheit)	108.7	122.2

a. The operational costs are calculated using average residential pricing in 2017 for natural gas and electricity from Energy Information Administration. Average annual costs are $0.13/kWh for electricity and $0.95/therm for natural gas (US EIA 2014).

Commercial Education Site 1 – Middle School

Com_Ed_1 is a large, multi-story brick school building surrounding by a large lawn, dotted with mature trees. The school enrolls 6th - 8th graders and has an enrollment of about 800 students. There is a swimming pool and cafeteria on-site.

Installation and Instrumentation

The DHW system for this case study has a large indirect hot water storage tank supplied by a dedicated boiler (Figure 22). The recirculation loop controlled and monitored has copper piping and the monitored recirculation loop serves classrooms (if necessary) and bathrooms.

Figure 22. Water storage tank and boiler at Com_Ed_1

Figure 23 shows the details on the installation for this site. Instrumentation and monitoring hardware followed the normal protocol. The plumbing piping had been upgraded to copper piping with fully wrapped and insulated pipes in the mechanical room. Because of this the operations staff was hesitant to cut into the piping. However, the system had a large number of temperature and pressure gauges installed in-line already. Some of these tees were utilized for the controller and field study instrumentation flow sensors (Figure 24 and Figure 25). For energy consumption data, runtime sensors were installed on the boiler and the recirculation pump. However, the system building automation system was also collecting data on this system. Both hot water flow and boiler operational status trends were set up.

Figure 23. Controller sensor and monitoring instrumentation installation locations at Com_Ed_1

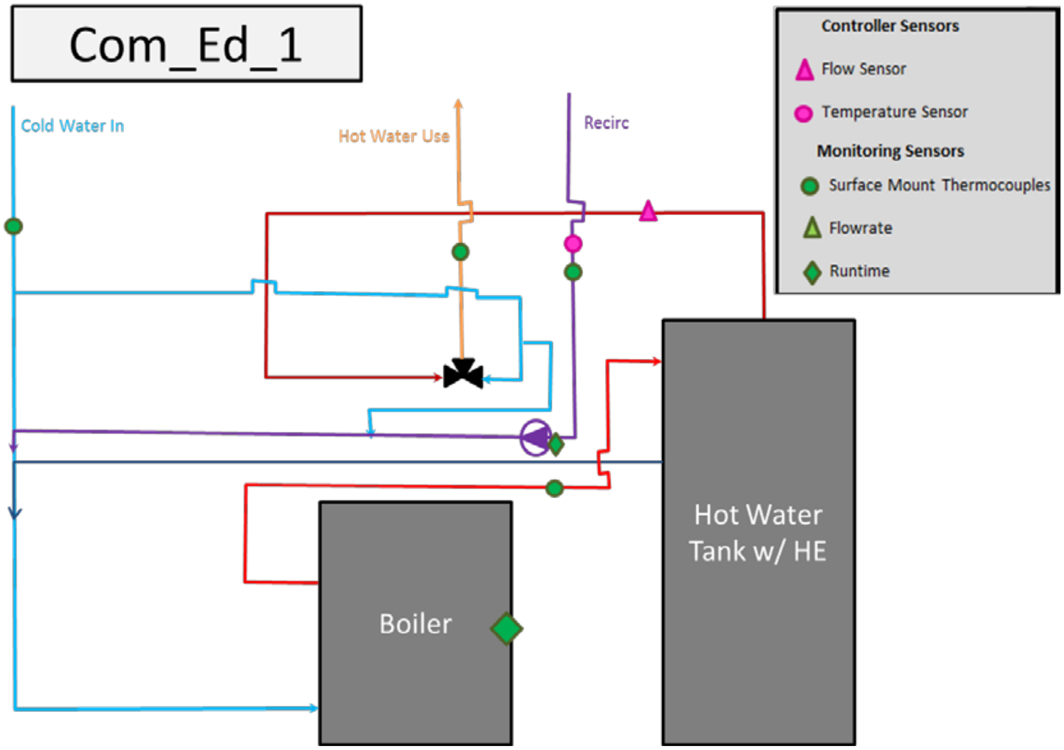


Figure 24. In-line temperature sensor that was replaced for the controller flow sensor

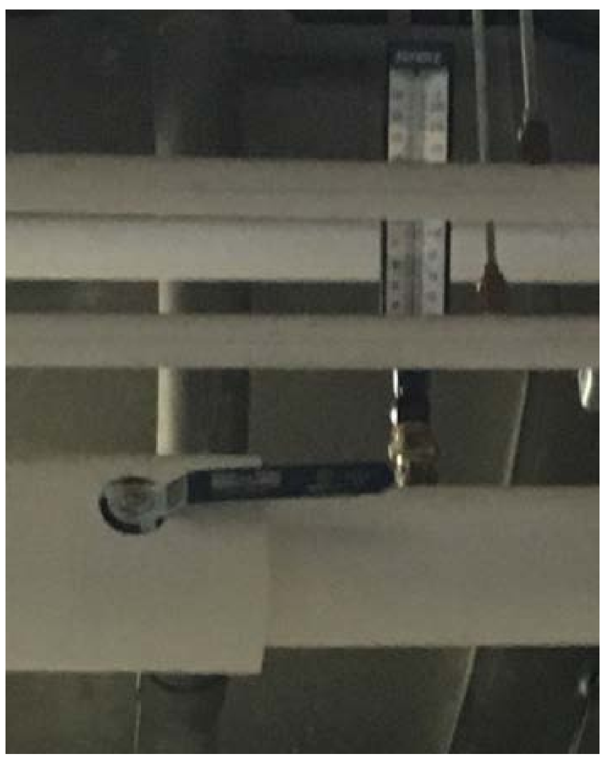
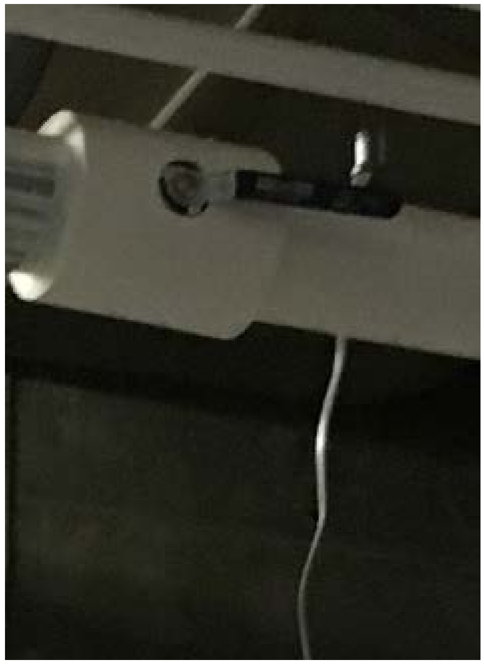


Figure 25. Installation of flow sensor replacing an in-line temperature sensor



Operation

The Building Automation System did not interact well with the controller. The controller cycled the recirculation pump on and off with DHW demand. This caused errors and alarms on the automation system. Operators attempted to silence or disable the alarms, but ultimately turned off the controller system without notifying the project team. These interruptions prevented any sufficiently long periods on controlled operation. Thus, detailed characterization was difficult for this site.

Analysis and Results

Unfortunately, due to the challenges, a sufficiently detailed dataset on this site was not available for complete analysis. Data that was collected did not allow for a full analysis of the on-demand system performance at this site, or any effects of seasonality on the on-demand recirculation system.

Commercial Education Site 2 – Middle School

Com_Ed_2 is a large one-story school building surrounding by paved parking areas and a large landscaped green belt, dominated by grass and a row of planted trees. The school enrolls 6th - 8th graders and has an enrollment of approximately 1,000 students. There is a swimming pool and cafeteria on-site.

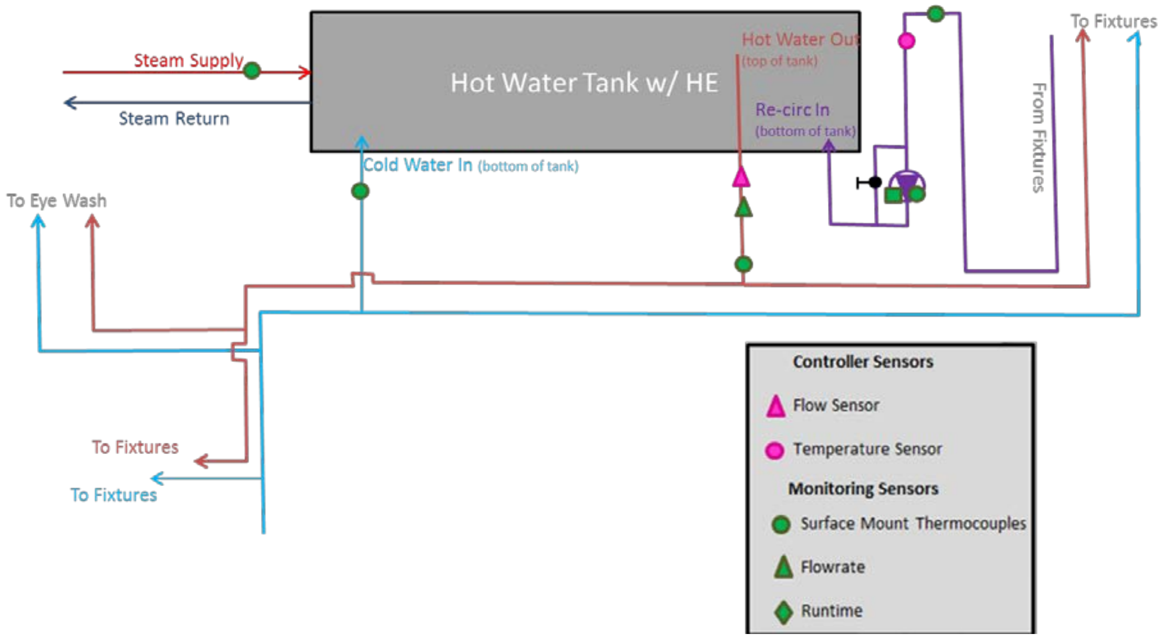
Installation and Instrumentation

The site has several DHW systems. The characterization project focused one of the systems that supplies hot water to a set of bathrooms and the pool locker rooms. The system consists of a 220 gallon storage tank supplied by an internal heat exchanger connected to a steam system (Figure 26). The storage tank feeds a single recirculation loop with copper distribution piping.

Figure 26. Indirect storage tank and recirculation look at Com_Ed_02

The distribution side of the DHW system at Com_Ed_2 was fairly typical and matched the standard install guides for the recirculation controller. The only difference form the standard installation was the location of the flow sensor. The typical location is on the cold inlet to the water heater. For this site the cold inlet pipe was an older 2.5” diameter cast iron pipe. The installer cautioned that cutting and disturbing pipes of this vintage and material can cause vibrations in the plumbing and create leaks at joints elsewhere in the system. The installer identified the hot supply from the tank as a preferred installation location. This location is also acceptable for the controller and documented in the installation literature. Figure 27 shows the location of the flow sensor and temperature sensor used by the controller. There was some complexity in the monitoring for this site. The energy use for heating the indirect heater was difficult to directly measure. The temperatures and runtimes of the stream heat exchanger were used to estimate the energy use (see operation and analysis and results sections below).

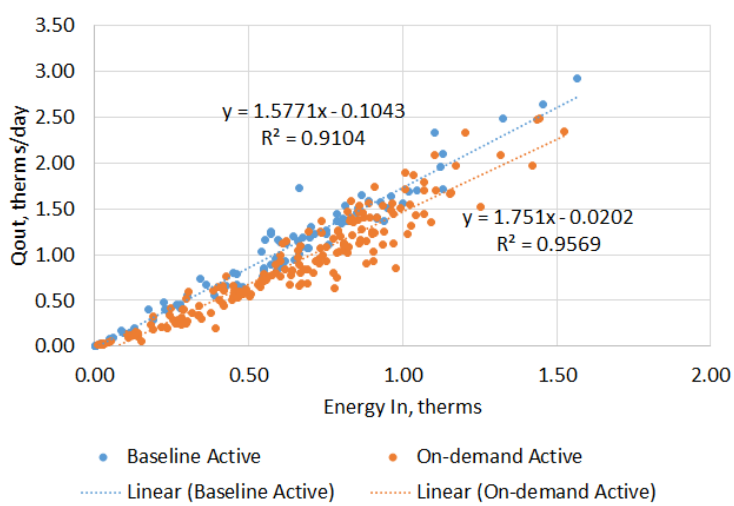
Figure 27. Instrumentation and sensor locations for Com_Ed_2



Operation

Com_Ed_2 was a unique site among the six locations in this demonstration pilot – the water heating system consisted of a 220 gallon insulated tank, supplied by a boiler-fed steam system. Much of the water use was for bathrooms, particularly for those off of the school's pool facility. This presented some challenges for effectively analyzing the performance of the on-demand recirculation system at the site. To determine the energy use, the energy into the system was calculated using the maximum heat transfer in the heat exchanger from the steam to the water loop. The boiler run times (estimated by changes in steam temperature) correlated with water draw patterns observed in the system (Figure 28).

Figure 28. Correlation of Energy In and Out for Heat Exchanger Calculation Method



The equation used to determine the maximum allowable heat transfer is as follows:

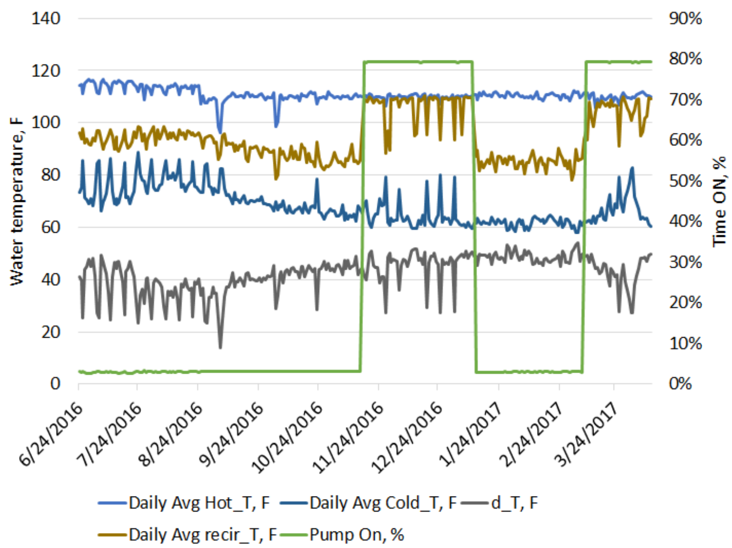
$$Q_{in} \sim Q_{max} = C_{min} \cdot \left(T_{in_{hot}} - T_{in_{cold}}\right)$$

$$= V \cdot \rho \cdot C_p \cdot (T_{steam} - T_{city})$$

Where *V* is the city water volume in cubic feet, *ρ* is water density based on city water temperature, and *Cp* is the water specific heat based on the average water temperature in and out of the water heater.

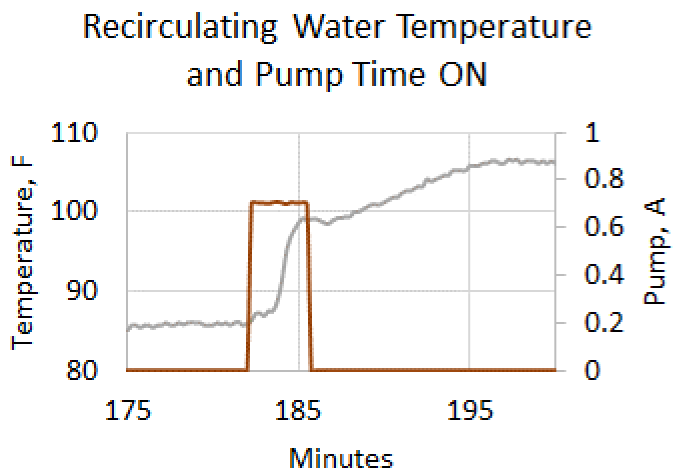
During the testing period, the data showed that the city water temperature had seasonality changes of a few degrees. The system did not show changes with the hot water set point of temperature rise. On the other hand, the recirculating water temperature showed significant change when the system operated in baseline mode (Figure 29).

Figure 29. COM_02 Effects on Hot Water and Recirculating Loop Temperatures



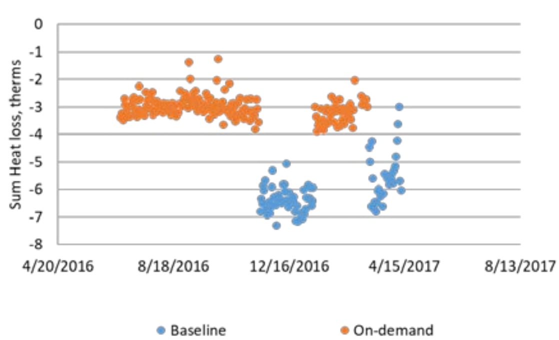
The research team also sought to understand whether there was any delay in the time it took for occupants to receive hot water while the system operated in either mode. The most straightforward way to determine this is to use temperature probes at the most distant fixtures (showers, sinks, etc.) and measure how long it took for the water leaving the fixture to reach the set point temperature. However, such monitoring is invasive and expensive, and was not within the budget for this project. Assuming that the ideal water temperature is close to 100°F, on a randomly selected day the time response for the recirculating water temperature to reach 100°F at the recirculation return measurement point is over 3 minutes (Figure 30). This measurement point is at the point where the recirculation loop return to the water heater and it is unknown where how far away the furthest room is from this location. Three minutes is a long time to wait for hot water, but this site reported no complaints or issues with hot water temperature. More detailed data collection would be necessary to completely answer this question.

Figure 30. COM_02 Recirculation Loop Temperature Response Time



The monitored data for both baseline and on-demand modes also suggested that recirculation line heat loss is a function of the operating mode rather than being driven by the outside air temperature, as might have been thought (Figure 31). The heat loss in the recirculation mode is reduced by more than half from6.5 therms per day in baseline to 3 therms per day in controlled mode.

Figure 31. COM_02 Recirculation Heat Loss and Operating Mode



The monitored data did not show evidence of the pump being activated by the falling loop temperature due to standby losses. During the on-demand control testing period, the pump usage was 3% regardless of water usage levels (Figure 32). Interestingly, it also appears that the pump was activated at the same time every day while operating in the on-demand mode. Figure 33 and Figure 34 show two different days with different water usage during the on-demand monitoring period.

Figure 32. COM_02 Pump Activation due to Standby Losses

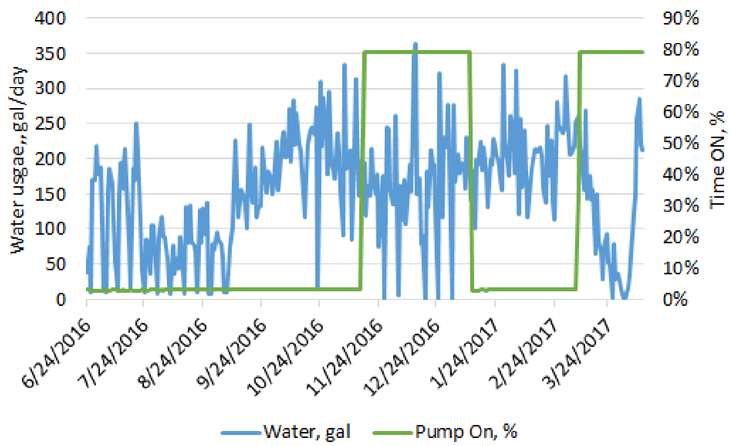


Figure 33. Two Days of Pump Runtime

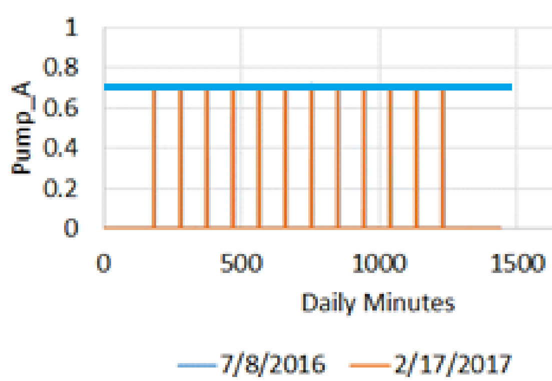
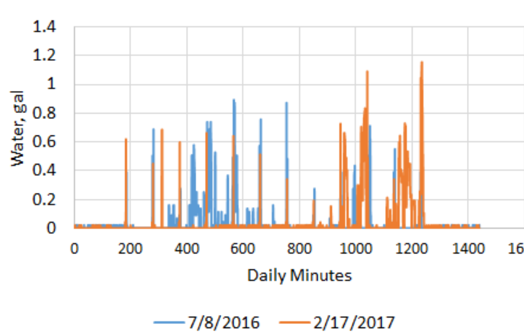
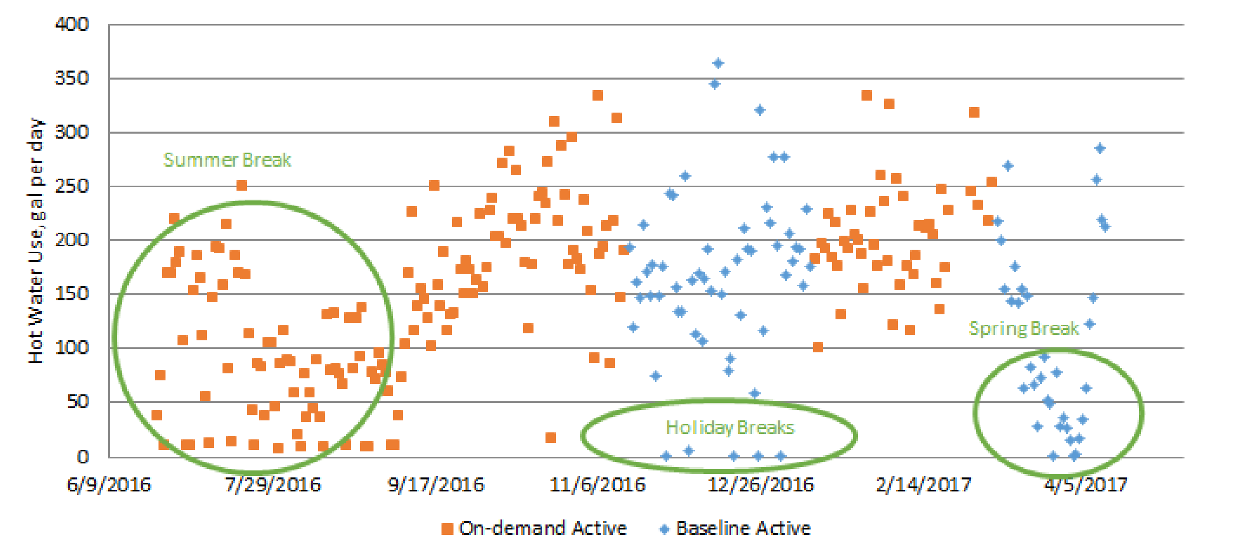


Figure 34. Corresponding Water Usage



Since Com_Ed_2 was a school building, the schools calendar year impacted the hot water usage in the building. The hot water system being monitored supplied water to locker and bathroom facilities near the pool and gym area. These facilities were used during the school periods, but were also open during some periods when school was out of session. Spring and summer breaks and the holiday season had clear impacts on the demand in the building (Figure 35). These calendar based variations impacted the analysis methodology.

Figure 35. Hot Water Use by date in Com_Ed_2



Analysis and Results

The collected data in each operational mode was analyzed to determine the weather normalized annual energy use. These annual energy usage calculations were then compared to determine the controller savings. The changing school and pool usage calendar at Com_Ed_2 made weather normalizing the annual energy calculations for each mode more complex than a standard field site. The various breaks in the school schedule and sporadic use of the pool facilities created a DHW load profile that was not dependent on inlet water temperature as was the case at other sites. In order to compare the hot water usage between the two operating modes the weekday, non-holiday hot water usage data was compared between December of 2016 and March of 2017. In this period inlet water temperature was consistent and remained between 58 and 64 ^{0}F (Figure 36).

During this comparable time frame, the baseline mode had an average hot water usage of 202.2 gallons per day of hot water use and a daily average hot water load of 0.827 therms. The demand controller mode used 202.3 gallons per day with and average load of 0.880 therms per day. This data determined the relative output or load profiles for each model. Figure 37 shows the relationships used to calculate the energy use based on the DHW load in each mode. This figure demonstrates the increased efficiency with the on-demand mode compared to baseline, as less energy was used to produce the same output.

Figure 36. Comparable inlet water and occupancy time for Com_ed_2

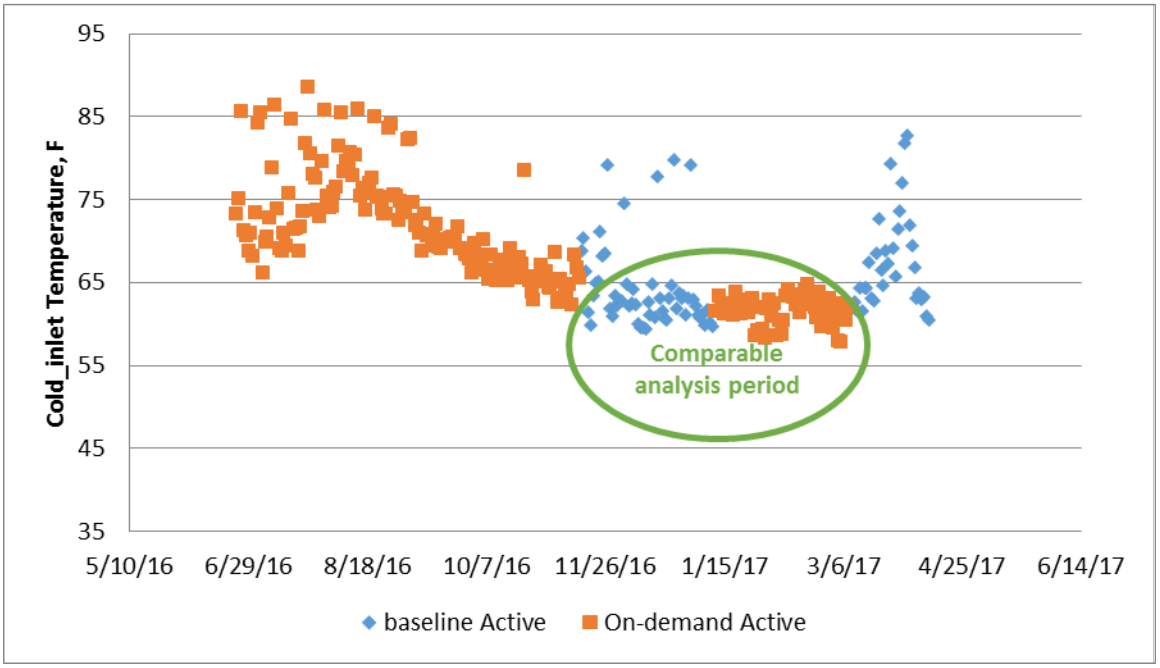


Figure 37. Energy consumption for demand and baseline modes at Com_ed_2

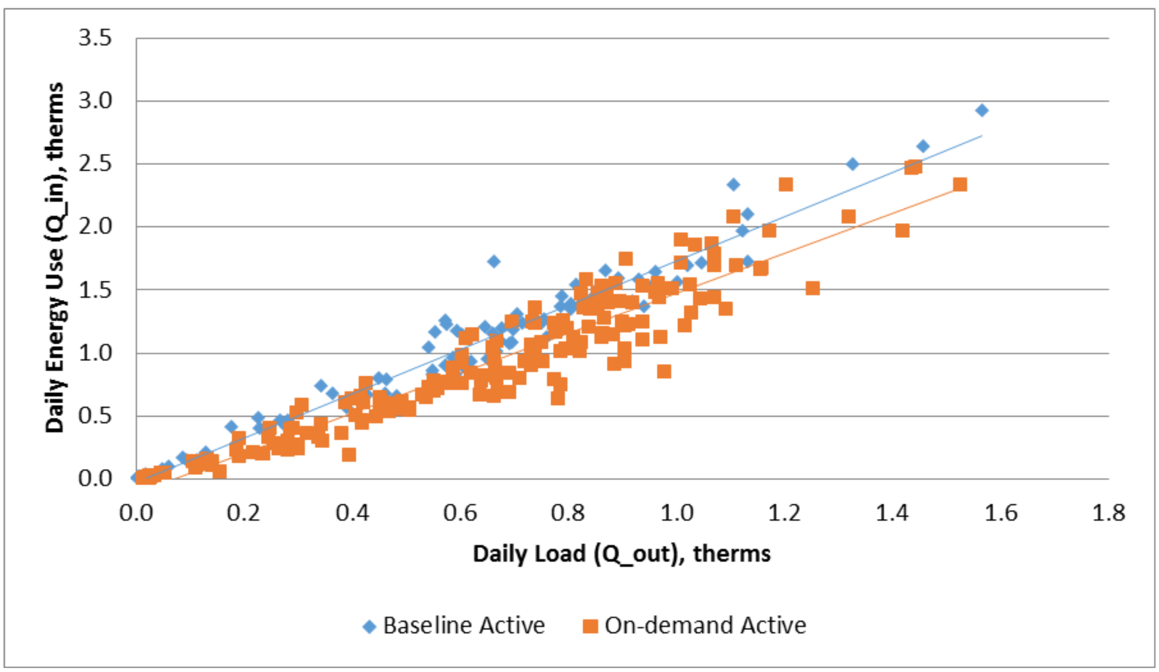


Table 18 summarizes these calculations with the on-demand saving a total of $149 per year a total cost savings of 30%, from a 476 MMBtu DHW energy use reduction.

Table 18. Summary of On-Demand and Baseline Results at COM_ED_02

Description	On-Demand Control Mode	Baseline Mode
Hot water use, gallon/day	165.3	165.2
Energy Delivered (Qout), therm/day	0.70	0.66
WH Energy Use (Qin), therm/day	1.01	1.14
Annual WH Use, therms	368	415
Annual WH Cost, $	$350	$395
Water Heater Savings	11.4%	N/A
Runtime Recirculation Pump, hours/day	0.7	19.0
Pump Electric Power, W	120	120
Pump Energy use, kWh/day	0.1	2.3
Annual Pump Use, kWh	32	830
Annual Pump Cost, $	$4	$108
Pump Savings	96.2%	N/A
Total Annual System Cost [a]	$354	$503
Total Savings	$149	N/A
Total Percent Savings	29.6%	N/A
Average Hot Water Temperature (degrees Fahrenheit)	111.2	109.8
Average Recirculation Loop Temperature (degrees Fahrenheit)	89.9	105.8

a. The operational costs are calculated using average residential pricing in 2017 for natural gas and electricity from Energy Information Administration. Average annual costs are $0.13/kWh for electricity and $0.95/therm for natural gas (US EIA 2014).

Commercial Site 3 – Office Building

COM_3 was an administrative office building in downtown St. Paul, MN. It is located in a highly urbanized area with small strips of lawn and trees lining some of the streets. The building consists of a three-story building attached by an enclosed connecting hallway to a larger, one-story building. A single recirculation loop serves the three-story building. That 80,150 square foot three-story building consists mostly of open office space. The DHW loop served the restrooms and small kitchenette facilities.

Installation and Instrumentation

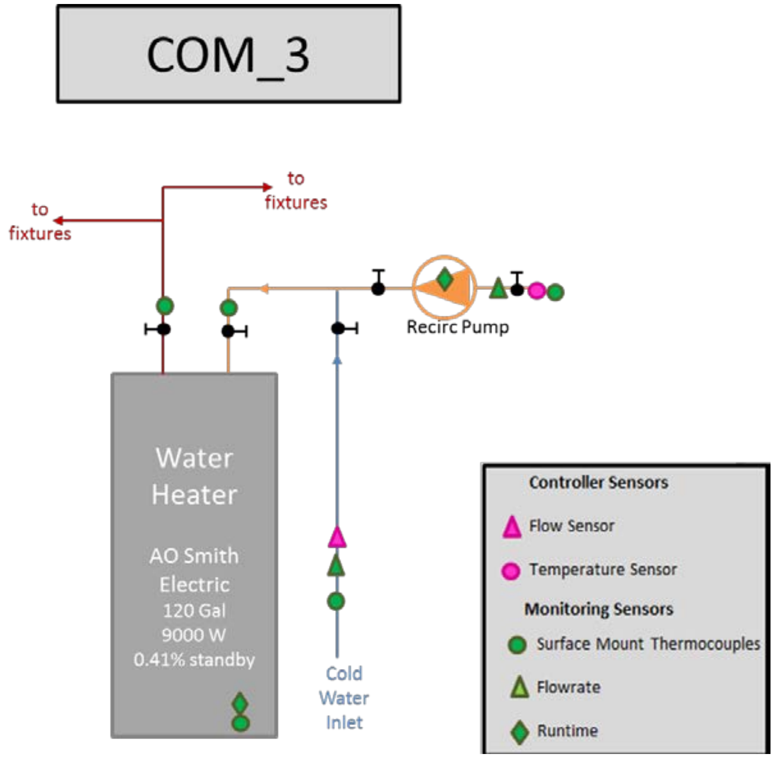
The domestic hot water system at COM_3 was a typical system for this building type. The hot water fixtures were served by a central DHW system with one water heater, one recirculation loop, and a single circulation pump (Figure 38).

Figure 38. Water heater and recirculation pump at Com_3

The physical installation of the control system and the necessary sensors was straightforward at Com_3. The flow sensor was installed on the cold water inlet to the system and the temperature sensor was strapped to the recirculation return pipe just prior to the recirculation pump (Figure 38 and Figure 39).

The flow sensor installation took approximately one hour to complete, but required the plumber to cut into the water heater inlet piping. It was necessary to shut-off water to the system during this time. Fortunately, the building had proper shut off valves and the isolation was easy to achieve. Taking the system offline required the work be performed after hours.

Figure 39. Instrumentation and controller sensor installation locations



Operation

There were several installation complications at Com_3 (See Appendix B: Field Log for full installation and commissioning log) that led to operational issues when the system was first commissioned. The issues fell into two categories. The first category was operation of the existing recirculation pump. There were a few pre-existing issues with the systems recirculation pump. These issues were not significant under the normal operation of the system, but were emphasized when the controller was operational, turning the pump on and off more frequently than normal. For example, the pump was missing a seal that was not leaky prior to the project, but each time the pump was stopped by the controller, there was a leak. A new seal was installed, as it should have been, and the problem was solved. The second type of problem was with the controller itself. The manufacturer has released a newer version of the controller and controller documentation to fix these issues, in part as a response to this installation. These types of controller problems consisted of:

1. The standard flow sensor and tee were too large for the piping used at this site (3/4" copper).
2. There was confusion over the labeling of the two control knobs on the controller.
3. A fuse within the controller had been blown at some point during the installation. This problem was not evident to any of the field staff.

Once the installation issues were understood and solved there were no additional operation issues reported at this site.

Analysis and Results

COM_03 showed an average 20.3% reduction in natural gas consumption for water heating and an 88% decrease in recirculation pump electricity consumption when operating in on-demand mode (Table 19).

Table 19. Summary of On-Demand and Baseline Results at COM_03

Description	On-Demand Control Mode	Baseline Mode
Hot water use, gallon/day	109.43	73.97
Energy Delivered (Qout), therm/day	0.46	0.35
WH Energy Use (Qin), therm/day	3.142857	3.942857
Annual WH Use, therms	1,147	1,439
Annual WH Cost, $	$4,369	$5,482
Water Heater Savings	20.3%	N/A
Runtime Recirculation Pump, hours/day	2.9	24.0
Pump Electric Power, W	370	370
Pump Energy use, kWh/day	1.1	8.9
Annual Pump Use, kWh	389	3,241
Annual Pump Cost, $	$51	$421
Pump Savings	88.0%	N/A
Total Annual System Cost [a]	$4,420	$5,903
Total Savings	$1,483	N/A
Total Percent Savings	25.1%	N/A
Average Hot Water Temperature (degrees Fahrenheit)	115.6	114.8
Average Recirculation Loop Temperature (degrees Fahrenheit)	96.8	106.8

a. The operational costs are calculated using average residential pricing in 2017 for natural gas and electricity from Energy Information Administration. Average annual costs are $0.13/kWh for electricity and $0.95/therm for natural gas (US EIA 2014).

A review of water usage showed no precise pattern on a daily basis, though there were weekly trends. Interestingly, these trends appeared to change depending on whether the system was operating in baseline or on-demand mode. In baseline mode, the system showed high water draws on Sundays and Mondays and low water draws on Fridays and Saturdays. In on-demand mode, high water draws were observed Sunday through Thursday, with lower draws on Fridays and Saturdays. It is unclear why the usage patterns appeared to change between the operating modes. Since the building is only open to the public Monday through Friday, we can only speculate what is driving the high water use on Sundays.

Perhaps a cleaning or maintenance crew may work on the building during weekend hours. Similarly, Friday may be a day when fewer staff members are on site, either working remotely, leaving the office at an earlier time, or being part-time employees. Discussions with the building manager did not shed any further light on the daily water usage patterns.

Apart from this unexpectedly high usage on Sunday, the fact that the usage appeared to differ depending on which operating mode the system was in warranted more investigation. Figure 40, below, shows that when operating in Baseline mode, total daily water use generally fell within three ranges: less than 50 gallons, 50 to 100 gallons, and over 100 gallons. In contrast, when operating in on-demand mode, total daily water use largely fell into two ranges: less than 50 gallons and, more often, more than 100 gallons. Figure 41 confirms this trend of higher usage while operating in on-demand mode (note that there is a period between modes where no valid data was collected).

Figure 40. COM_03 Average Water vs. Energy Used on a Daily Basis

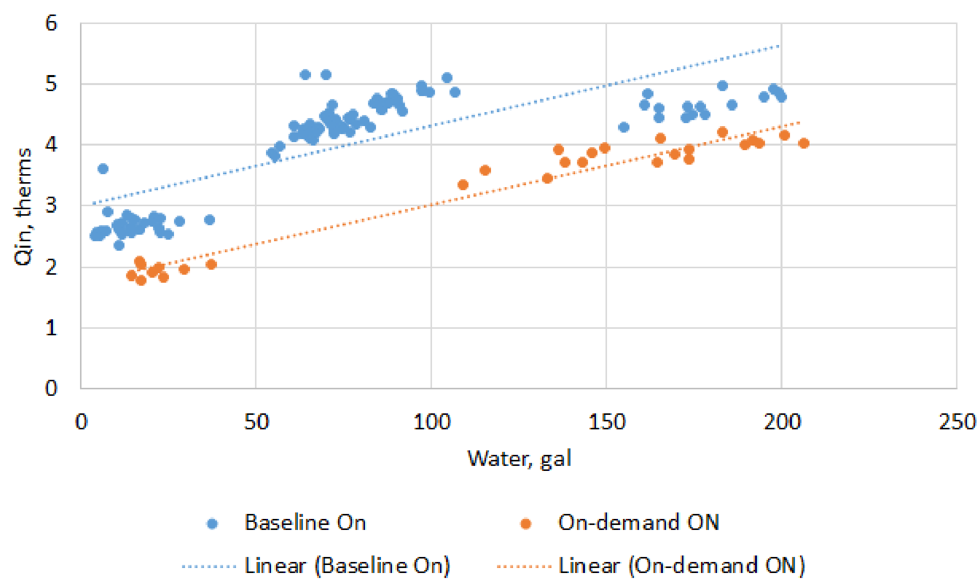
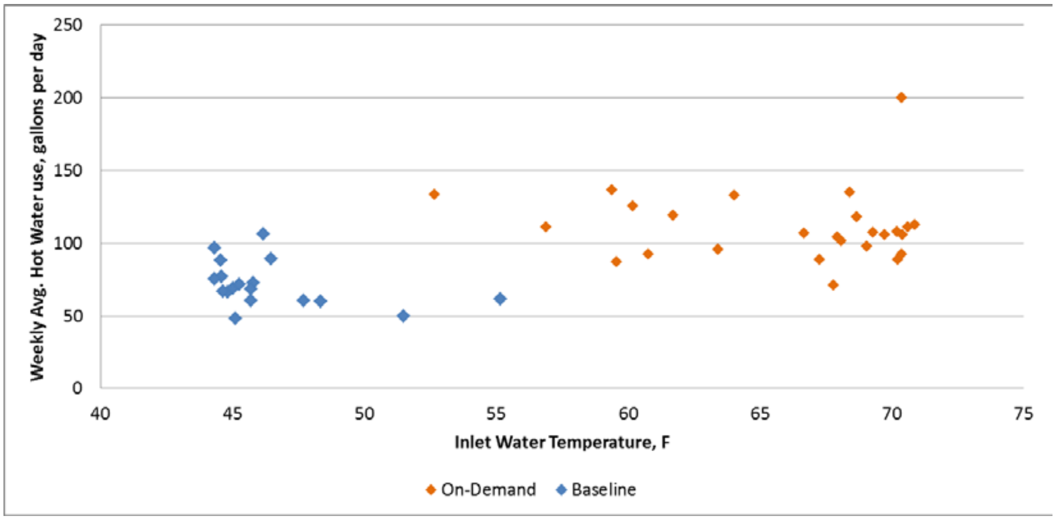


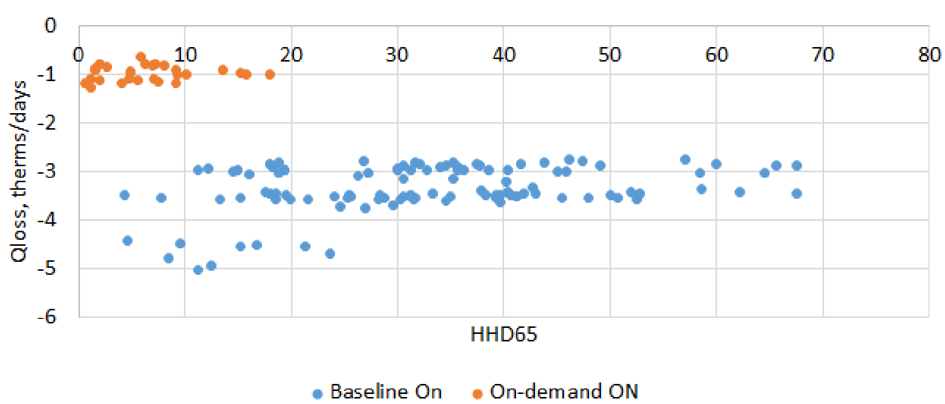
Figure 41. COM_03 Average Weekly Water Usage



Hot water draw temperatures were found to be stable throughout the entire testing period, regardless of operating mode, though the recirculating water temperature was on average about 10°F lower in on-demand mode than baseline mode. While the project team cannot conclusively say what is driving this difference, we believe that these two findings – the higher average daily water usage by the on-demand control and the lower average recirculation loop temperature – may relate to one another. It may be indicative of longer water run times when the system operates in on-demand mode if the water isn't reaching a comparably hot temperature as the baseline system. However, there may be additional factors at play, such as changes in personnel, building operations, auxiliary equipment, etc., that were outside of the scope of work to monitor for this project.

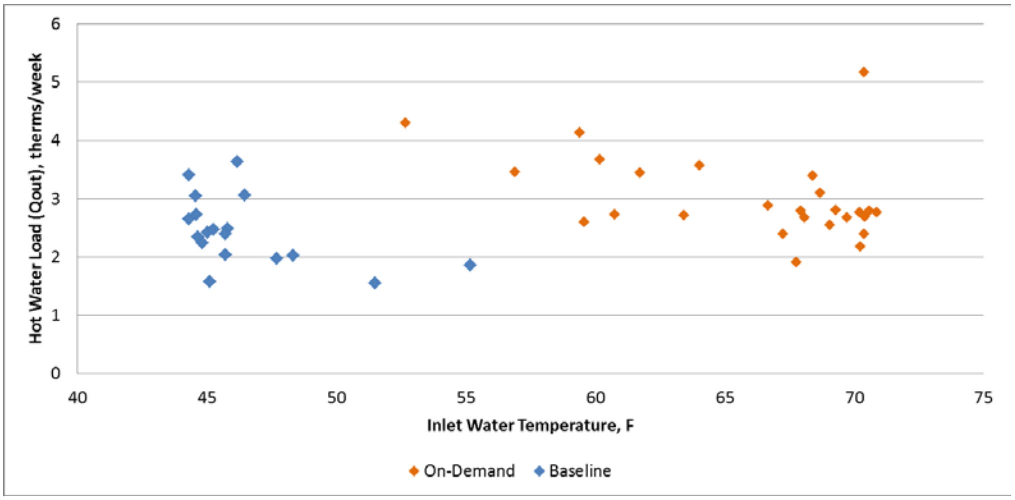
Seasonal impacts were studied through analyses of heating degree days (HDD) and the water temperature of the city water in the cold inlet pipe. A strong, predictable relationship was not observed between recirculation loop heat loss and HDD. Distribution line heat losses were reduced by 25% when operating in on-demand mode (Figure 42).

Figure 42. COM_03 Distribution Heat Losses vs Heating Degree



Although recirculating lines are not significantly influenced by outside air temperatures, there was a relationship between water usage totals and the cold water temperatures. Figure 43 shows the impact of the cold inlet water temperature on the DHW energy delivered to the building.

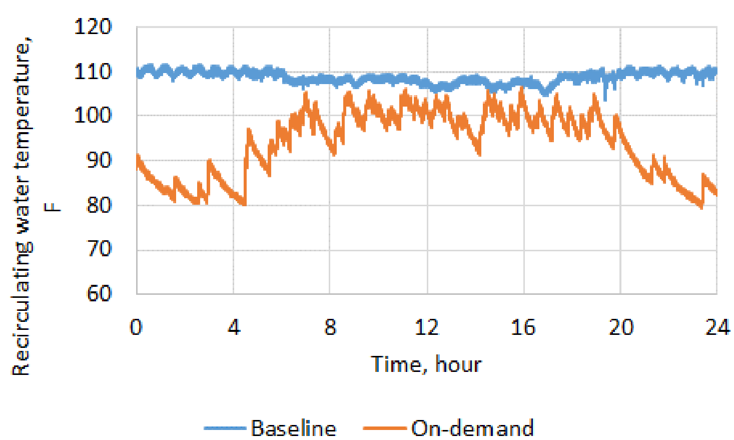
Figure 43. Seasonal impacts of inlet water temperature on the DHW load of the building



Based on analyzing different water draw volume days, it was estimated that the pump turns on 6% of the time in an hour (i.e., for 3.6 minutes) when the water draw volume is zero.

The team also wanted to gauge the response time of heating the water in the recirculation loop in on-demand compared to baseline modes. On a high water usage day, the on-demand control would slowly raise the average loop temperature (Figure 44).

Figure 44. COM_03 Recirculation Loop Temperature Response Time



The research team also sought to understand whether there was any delay in the time it took for occupants to receive hot water while the system operated in either mode. Assuming that the ideal water temperature is close to 100°F, on a randomly selected day the time response for the recirculating water temperature to reach 100°F at the recirculation return measurement point is 5 minutes (Figure 45 and Figure 46). This measurement point is at the point where the recirculation loop return to the water heater and it is unknown how far away the furthest room is from this location. Five minutes is a long time to wait for hot water, but this site reported no complaints or issues with hot water temperature. More detailed data collection would be necessary to completely answer this question.

Figure 45. COM_03 Period of Time for Temperature in recirculating loop to reach 100F on Randomly Selected Day

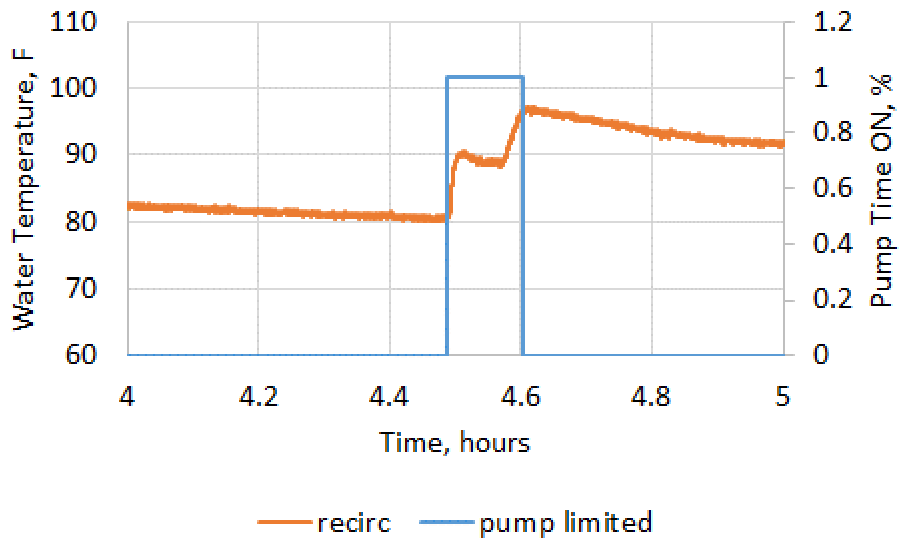
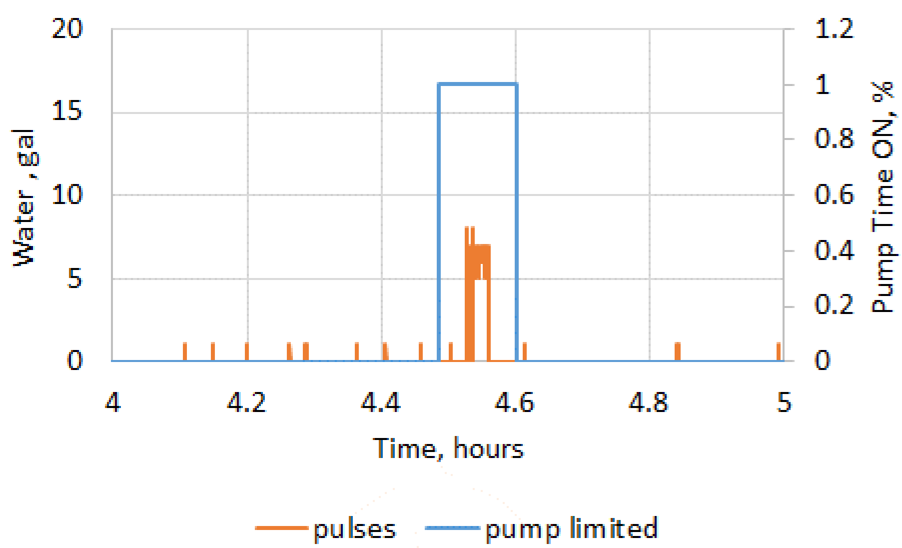


Figure 46. COM_03 Period of Time Pump is activated to reach 100F on Randomly Selected Day



Summary and Discussion of Results

Summary of Energy Use Results

As discussed in the case studies full data analysis was only possible at 4 of the 6 sites. The results for these sites (Table 20) show consistent positive savings. On average 14% of the energy to heat the hot water, as well as 87% of the pumping energy was saved.

Table 20. Annual Energy Use Results for all Sites

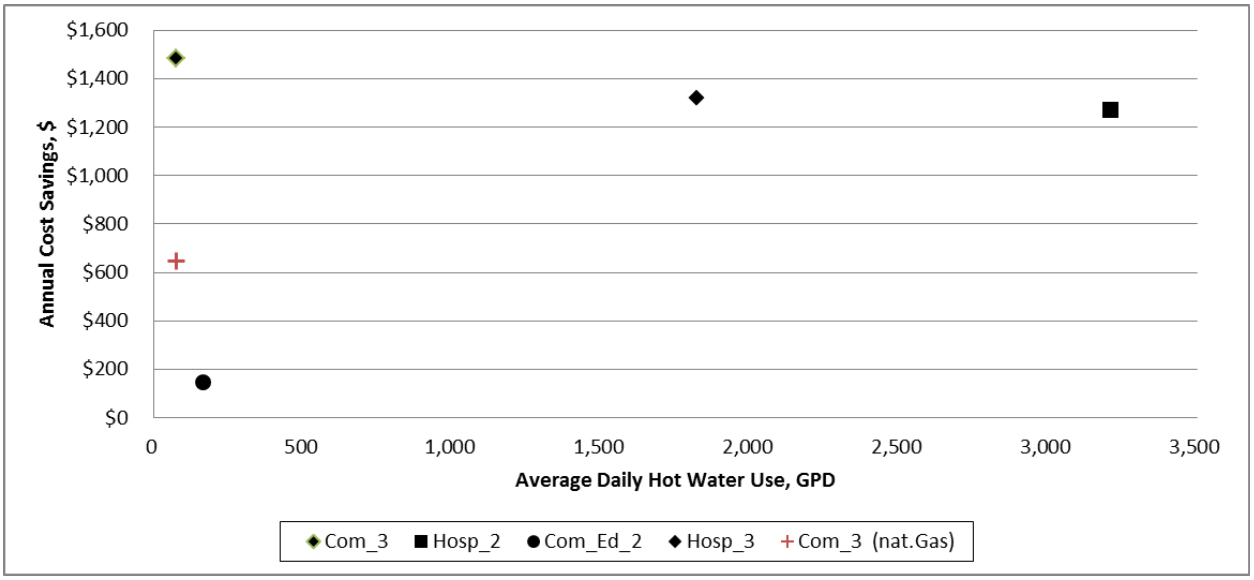
Mode	Measurement	Hosp_02	Hosp_03	Ed_02	Com_03 [b]	Average
Baseline	Thermal Use (therms)	9,965	8,211	415	1,439	5,008
	Electrical Use (kWh)	3,679	675	830	3,241	2,106
	HW Used (gal/day)	3,210	1,822	165	74	1317.75
	Operating Cost [a]	$9,945	$7,888	$503	$5,903	$6,060
Control	Thermal Use (therms)	8,979	6,907	368	1,147	4,350
	Electrical Use (kWh)	1,104	47	32	389	393
	HW Used (gal/day)	3,210	1,822	165	109	1326.5
	Operating Cost [a]	$8,674	$6,568	$354	$4,420	$5,004
Difference	Thermal Use (therms & %)	986	1,304	47	292	657.25
		9.9%	15.9%	11.4%	20.3%	14.38%
	Electrical Use (kWh & %)	2,575	627	799	2,852	1,713
		70.0%	93.0%	96.2%	88.0%	86.80%
	HW Used (gal/day & %)	0	0	0.2	35	8.8
		0%	0%	0%	32%	8%
	Operating Cost ($ & %) [a]	$1,271	$1,320	$149	$1,483	$1,056
		12.8%	16.7%	29.6%	25.1%	21.05%

a. Natural gas price of $0.95/therm and electricity price of $0.13/kWh, based on the average pricing from the Energy Information Administration (US EIA 2014).

b. Com_03 had an electric water heater.

While the percentages saved are relatively consistent the total energy and cost savings vary widely with hot water load. Buildings with large water usage, have bigger DHW systems, with bigger pipes and higher flow rates. These larger systems have higher loses and more potential for savings (Figure 47). Com_3 had an electric water heater, which significantly increased the savings potential. Figure 47 shows the reduction in annual savings if the site performed exactly the same, but used natural gas instead of electricity ($1,500 with electric to $650 with gas).

Figure 47. Impact of hot water use on the savings at each site



Using the measured water heating loads and energy savings of the demand controller, the theoretical savings estimates can be updated. Table 21 shows the thermal and pump energy savings across several commercial building sectors (Table 8 and Table 9 updated with measured data). These tables show the potential of these systems in MN building stock.

Table 21. Theoretical Savings of On-Demand Controllers based on the Measured Energy Savings.

		Theoretical Savings			Updated Technical Potential		
Type	Number of Establishments	Market Penetration	Total Annual Gas Savings (therms)	Total Annual Electric Savings (kWh)	Market Penetration	Total Annual Gas Savings (therms)	Total Annual Electric Savings (kWh)
Hospitality	2,536	100%	3,525,040	3,928,264	10%	352,504	392,826
Colleges, Universities, & Professional Schools	102	100%	92,004	169,320	10%	9,200	16,932
Nursing, Mental Health & Residential Care Facilities	482	100%	434,764	800,120	10%	43,476	80,012
TOTAL	3,120		4,051,808	4,897,704		405,181	489,770

Cost-Effectiveness

The cost effectiveness of these installations depends on the overall water heating load. The installation costs were relatively consistent across the six sites. For sites with one flow sensor, as will be the case on the vast majority of the jobs the average installations were completed in about 4 hours and cost was $887[5]. The controller and control sensors cost $1,095. For the single site that used three flow sensors the installation cost was not significantly different, but the sensors and controller cost $1,635. All six installations used the existing recirculation pump. The manufacture noted that for some installations a new pump may be necessary. For these installations a pump and controller package can be purchased for a cost of $1,395 to $1,900 depending on the required pump. The average total installed cost for this project was $2,072. Table 22 shows the installation costs and paybacks at each site.

Table 22. Paybacks for each of the sites

	Hosp_1	Hosp_2	Hosp_3	Ed_1	Ed_2	Com_3 [b]	**Average**
Controller & Sensor Cost	$1,095	$1,635	$1,095	$1,095	$1,095	$1,095	$1,185
Installation Cost	$845	$1,033	$1,228	$422	$817	$975	$887
Total Cost	$1,940	$2,668	$2,323	$1,517	$1,912	$2,070	$2,072
Operating Cost Savings	$1,974[a]	$1,271	$1,320	NA	$149	$1,483	$1,239
Payback	1.0	2.1	1.8	NA	12.8	1.4	1.7

a. Saving used for this calculation at Hosp_1 are based on the hot water usage and the estimated savings from the other 4 sites, not actual measured savings.

b. Com_3 required the installation to be after business hours and the plumber charged after-hours rates.

Figure 47 shows the hot water use in a building has a significant impact on the annual savings. Buildings, like the hotels monitored in this project, that use 1,500 or more gallons of hot water a day will have paybacks around two years. Buildings that use significantly less hot water, like the office and education building monitored for this project, will have longer paybacks (Table 23). Additionally, the increased cost per BTU of electric water heating significantly increases the savings and shortens paybacks for electrically heated DHW systems.

[5] This install cost did not include any additional contractor or project staff time for troubleshooting or commissioning issues found in the DHW systems or controller installs. The $887 does include some non-labor costs, including materials.

Table 23. Simple paybacks for demand controlers for average field characterization results

Building	Hot Water Use (GPD)	Annual Savings	Install Cost	Payback (years)
Hotel: Typical install	>1,500	$1,300	$2,132	1.6
Hotel: Complex Install	>1,500	$1,300	$2,668	2.1
Commercial	<200	$400	$1,833	4.6
Commercial: Electric WH	<200	$900	$1,833	2.0

a. Note that installation costs, savings, and paybacks for both the commercial and commercial electric water heater results are based on the averaged performance of Com_Ed_2 and Com_3. For example for the gas water heater average the results from Com_3, which had an electric water heater, were estimated had the water heater used natural gas instead.

Discussion of Results

The percentage energy savings results closely matched our expected savings leading into the project. Thermal savings were 14% on average with an additional 87% of the pump energy saved. The total annual thermal energy savings were close to the range of expected savings, but were largely load dependent. These savings dropped below the expected range, in the smaller use commercial buildings. Pump energy savings were in-line with the expected savings for the demand controller (Table 24). It is important to note that the sample size of this field project was too small to draw conclusions on the actual DHW load from this building sector.

Table 24. Comparing Actual savings to expected savings

Savings Estimate	Expected – Low Estimate	Expected - Likely Estimate	Expected – High Estimate	Actual – Hosp_2	Actual – Hosp_3	Actual – Com_ed_2	Actual – Com_3
Thermal (Therms/year)	668	1,431	2,098	986	1,304	47	292
Pump Energy (kWh/year)	500	750	1,250	2575	627	799	2852

This field project confirmed the percentage reductions in water heating energy and recirculation pumping energy help for commercial and hotel buildings in Minnesota. However, a quality installation with proper commissioning was necessary before these savings were achieved. As discussed in the case studies for each site, complexities of individual installations can complicate the quality installation. The manufacturer has indicated that installations in multi-family buildings in California have become common-place. These systems are likely to be similar to the systems in Hospitality and Commercial buildings. Each of the six test sites in this study required at least one additional visit to ensure the controller was operating correctly. These additional commissioning visits were necessary either due to complications in how the controller's instruments were interacting with the system, or because there were operational concerns with the existing system.

Design and instrumentation

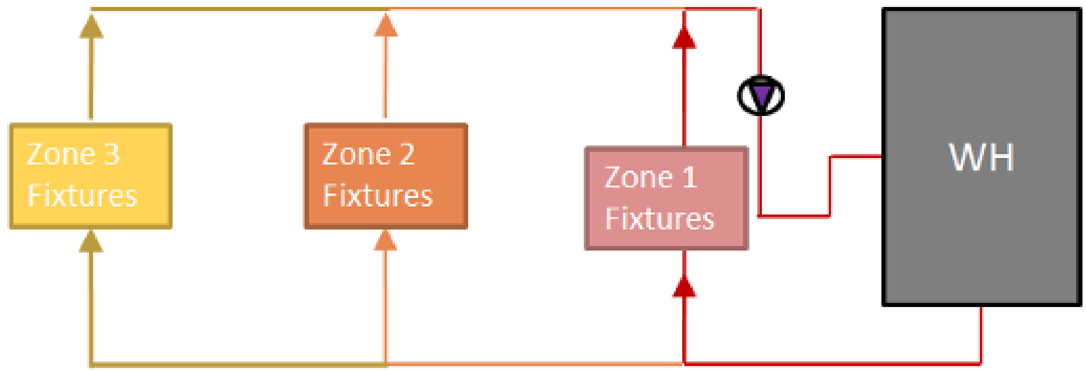
There were a set of issues dealing with the application of the controller. Most of these issues related to the controllers installation procedure being designed for a standard multi-family DHW system design. The controller was designed to sense a single flow and measure a single temperature. Variations for the standard DHW design impacted the meaning of that flow and temperature measurement, which lead to the controller operating on partial or incorrect information. Some of these variations included:

- Laundry facilities that required high supply water temperatures sharing water heaters or storage tanks with a guest room recirculation loop
- DHW systems that have a multiple redundancies, in storage volume, heating source, and/or plumbing. These redundancies lead to flow paths and systems operating in ways that were difficult to monitor and control.
- Hotel and commercial properties had multiple recirculation loops more often than was expected prior to this project.
- This building sector, at least in Minnesota, had a wide variety of heating plants, including water heaters, dedicated DHW boilers, combined space and water heating boilers, and district steam systems.

Cross-over and balancing

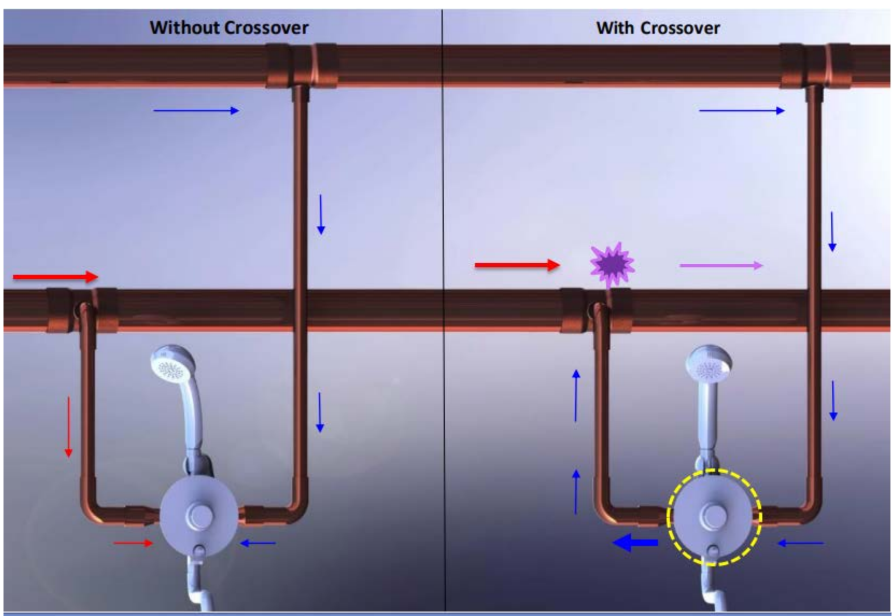
Balancing issues occur when a zoned system has different flow rates through different parts of the system. Without proper balancing with check and balancing valves a system with a single pump and multiple zones (Figure 48) will operate at a range of flows and temperatures. For example, the first zone, closest to the heat source and pump has the highest temperature and flow rate. The next zone will be further from the pump and have lower flow rates and lower temperatures and the furthest zone will have even lower flows and temperatures. These temperatures are mixed together at the recirculation pump. In continuous operation the flow rate and temperature are increased until the furthest zone is satisfied, which wastes additional energy, but meets the occupants needs. In demand control mode, the controller senses the combined flow and temperature. Controlling on the average temperature means the lowest flow and temperature zone will be undersized if the system is not properly balanced.

Figure 48. A central DHW system with zoned circulation



In a system with cross-over has water crossing from the cold side of the system into the hot, or vice versa. This typically happens through a pressure imbalance and a failure in a mixing valve. For example, Figure 49 shows a system with a shower mixing valve working properly and one that has failed. In the failed case, cold water may pass through the cold side of the valve into the hot water supply line, reducing the water temperature in the hot loop. If the problem is large enough this can reduce the water temperature in the entire loop. Continuous recirculation hides this problem, because the hot supply from the water heater keeps circulating and reheating the hot line.

Figure 49. Cross-over through a failed shower valve in a central DHW system.



Conclusions and Recommendations

Energy savings percentages were consistent across the field sites but varied by building type, due to the differences in hot water load. The installations costs were very similar across all building types. In applications where the energy costs associated with hot water use and circulation are high the paybacks will be less than two years. The savings and paybacks are significant enough to warrant inclusion in energy efficiency programs, but installation and operation of these controls can be difficult in more complicated system designs.

Program Recommendations

The energy savings, both in natural gas and electricity use, were significant enough for this project to include this technology in Conservation Improvement Programs (CIP). Programs designed facilitate the installation of a DHW recirculation controller should consider the best market segments to ensure a successful program with large savings and short paybacks. The flowing criteria will ensure a good performance and significant energy savings.

1. The hot water should be supplied through a central DHW system.
2. The central systems' distribution should use a recirculation loop or loops with continuous operation for at least eight hours per day.
3. The central DHW systems should use at least 500 gallons of hot water per day.
4. The controller manufacturer's installation documentation should be followed, including control sensor placement location and controller operation parameters. For unique installations that must deviate from the recommended installation, the manufacturer or a manufacturer-approved installer should be consulted.
5. Building operators and the installing contractor should know and understand the DHW system design, distribution loop, fixtures, operating conditions, and system heat source (water heater). In more complex DHW systems, it is necessary for the installer to understand the flow paths and plumbing design is necessary to ensure the sensors are measuring in the correct locations. For example if a recirculation system has multiple zones and the recirculation pump on the first zone is controlled, the second zone can keep a shared recirculation return line warm, preventing the controller from turning on the pump in the first zone, resulting in cold water. Meeting these five criteria will result in a straightforward installation that yields significant energy savings, delivers adequate performance, and has a good payback.
6. The DHW system should be tested for pre-existing issues prior to installation of an advanced controller. Hot water system issues, such as cross-over and unbalances recirculation zones, can be hidden by the large hot water wastes in continuous recirculation. Eliminating the waste with a demand controller can highlight and expose these problems.

Meeting these five criteria will result in a straightforward installation that will yield significant energy savings, deliver adequate performance, and have a good payback.

Deemed Savings Calculations

Once a quality installation is preformed the deemed energy savings can be estimated with a simple calculation for each fuel type.

Thermal Energy Savings

$$Annual\ Thermal\ Savings\ (MMBtu) = C_m * C_u * GPD_h * 365 * (T_{Supply} - T_{main}) * \left(\frac{1}{eff_{syst}}\right) * RT_{frac} * Sav_{thermal}$$

Where

C_m = a materials constant for the properties of water = 8.3

C_u = a unit conversion factor = 1/1,000,000

GPD_h = daily hot water volume in gallons, if unknown, see Table 25.

T_{supply} = hot water supply temperature = 125 ^{o}F

T_{main} = main water temperature incoming to the building = 60 ^{o}F

Eff_{sys} = System efficiency accounts to the water heater efficiency as well as the distribution efficiency = 0.55

RT_{frac} = fraction of the day the recirculation pump is running in baseline mode

$Sav_{thermal}$ = the estimated thermal savings for the demand controller, based on the results from this project = 12%

Table 25. Hot water Use for Various Types of Buildings (ASHRAE 2015)

Type of Building	Average Daily Use
Motels:	
20 units or less	20 gal per unit
60 units	14 gal per unit
100 units or more	10 gal per unit
Office Buildings	1 gal per person
Elementary Schools	0.6 gal per student
Junior and Senior high schools	1.8 gal per student

Electrical pump savings

$$Annual\ Pump\ Savings\ (kWhr) = C_u * P_{pump} * RT * 365 * RT_{frac} * Sav_{pump}$$

C_u = a unit conversion factor = 1/1,000

P_{pump} = pump energy consumption in Watts, if known assume 125 W.

RT = hours of the day the recirculation pump is running in baseline mode

RT_{frac} = fraction of the day the recirculation pump is running in baseline mode = RT/24

$Sav_{thermal}$ = the estimated pump savings percentage for the demand controller, based on the results from this project = 87%

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Appendix A: Instrumentation Plans

Instrumentation Key

Controller:

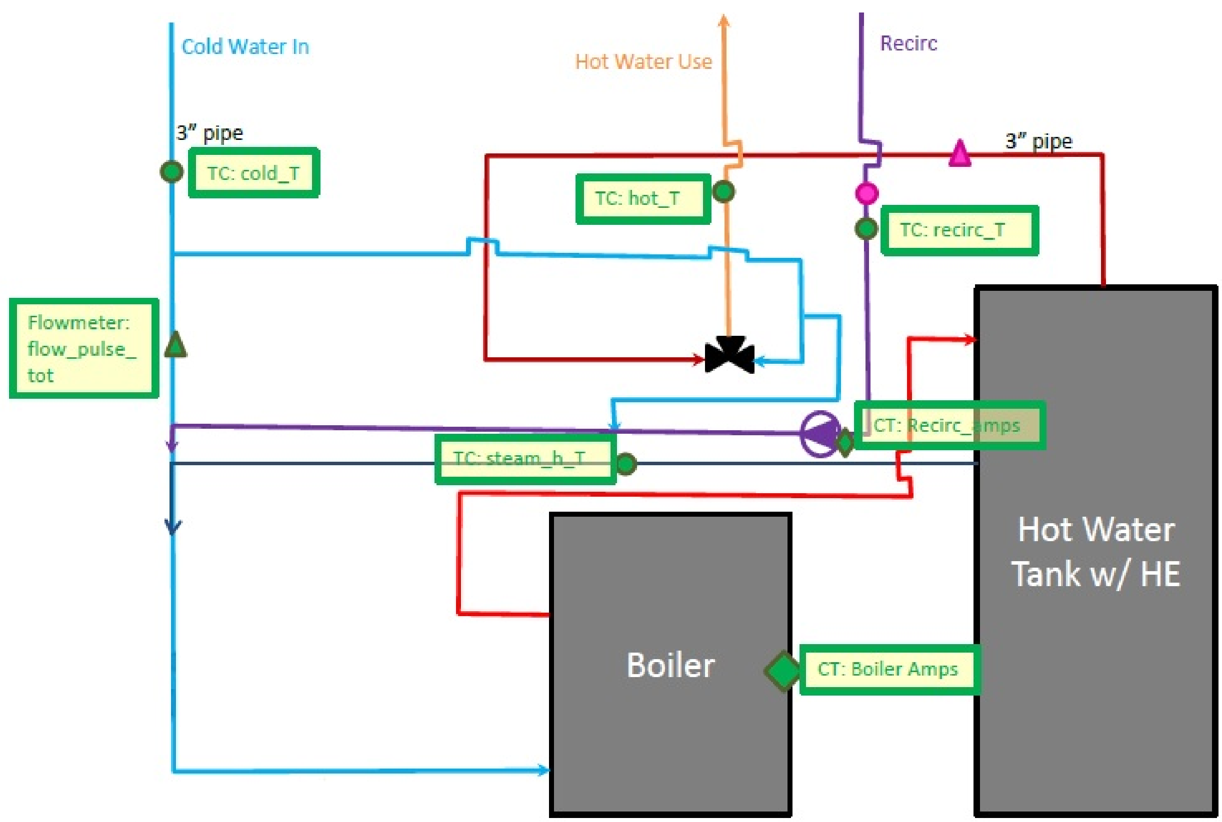
- Flow Sensor
- Temperature Sensor

Data Monitoring:

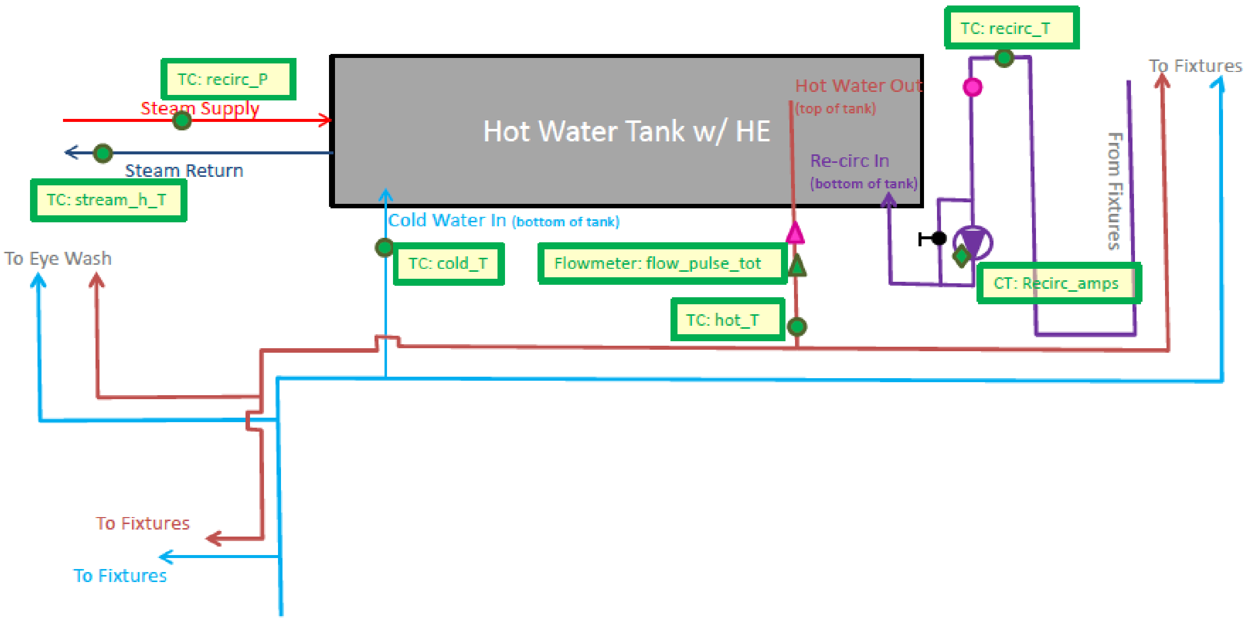
- Surface Mount Thermocouples
- Hobo on/off logger
- Runtime

Instrument type: Data Logger Variable Name

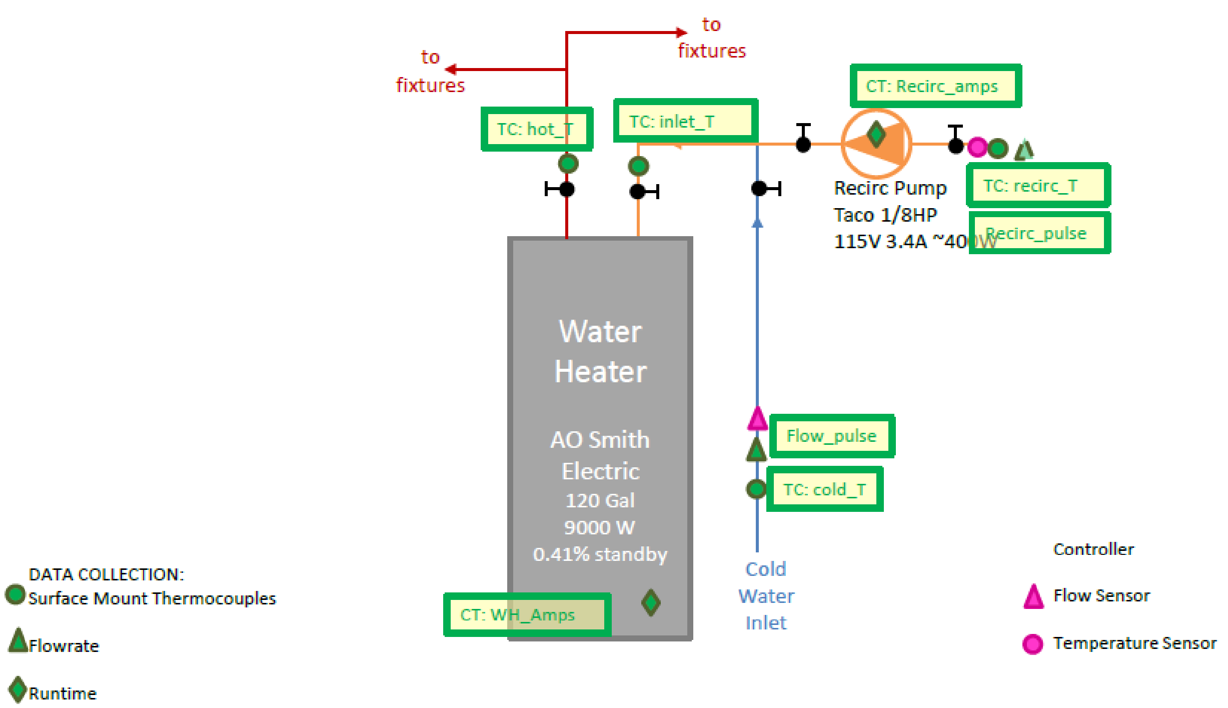
Com_Ed_1 Middle School



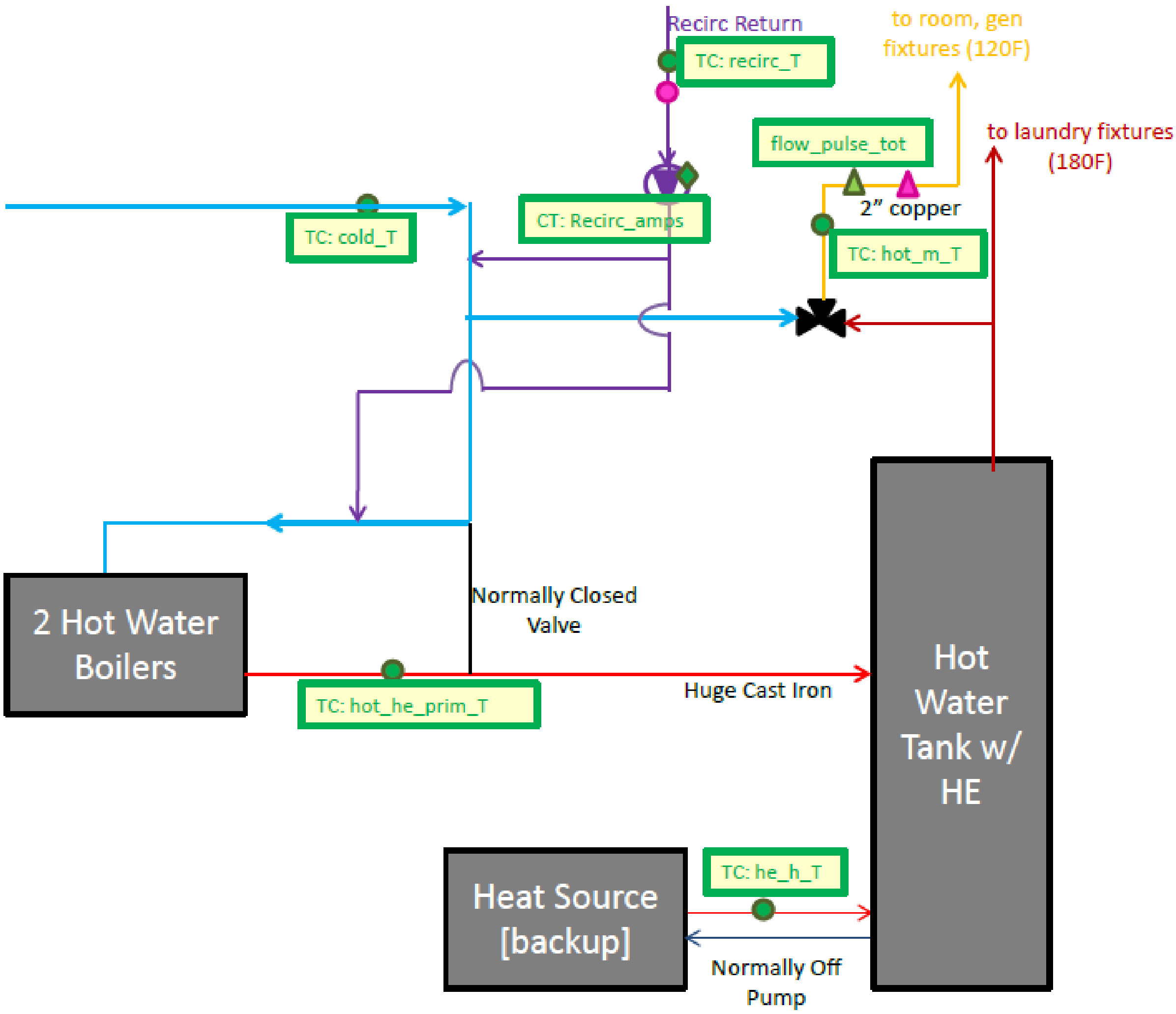
Com_Ed_2 Middle School



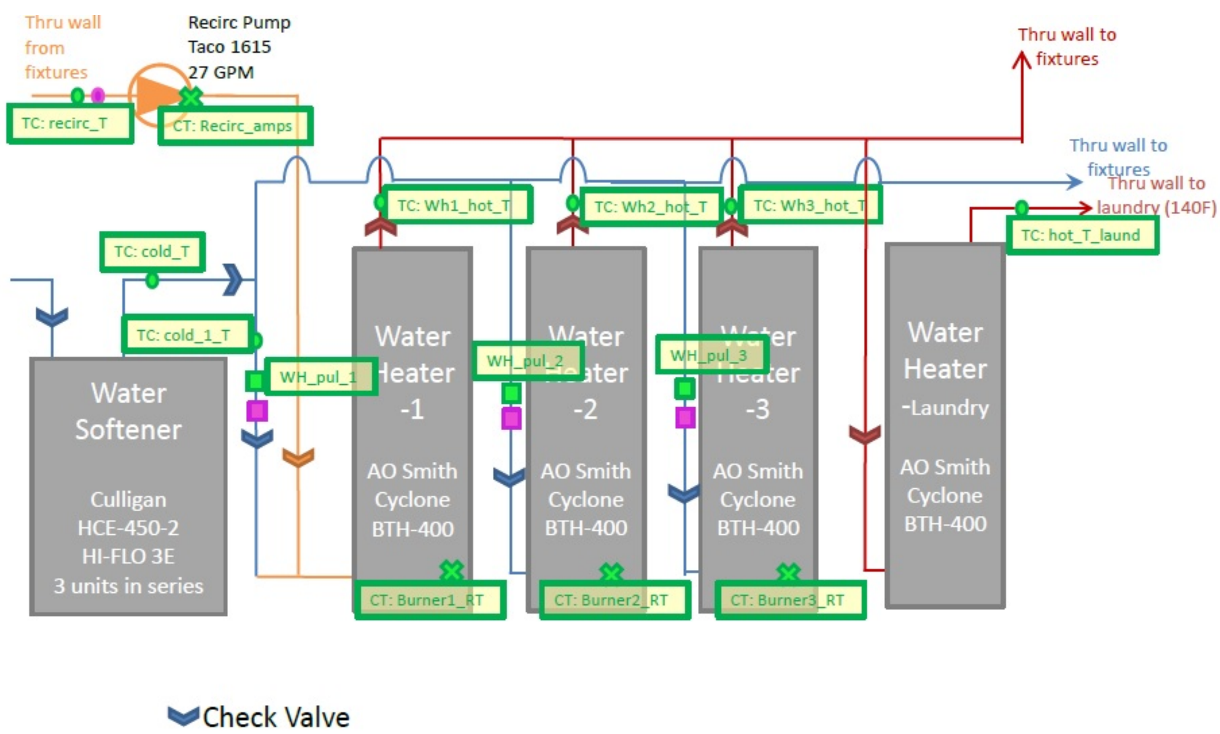
Com_03 Office Building



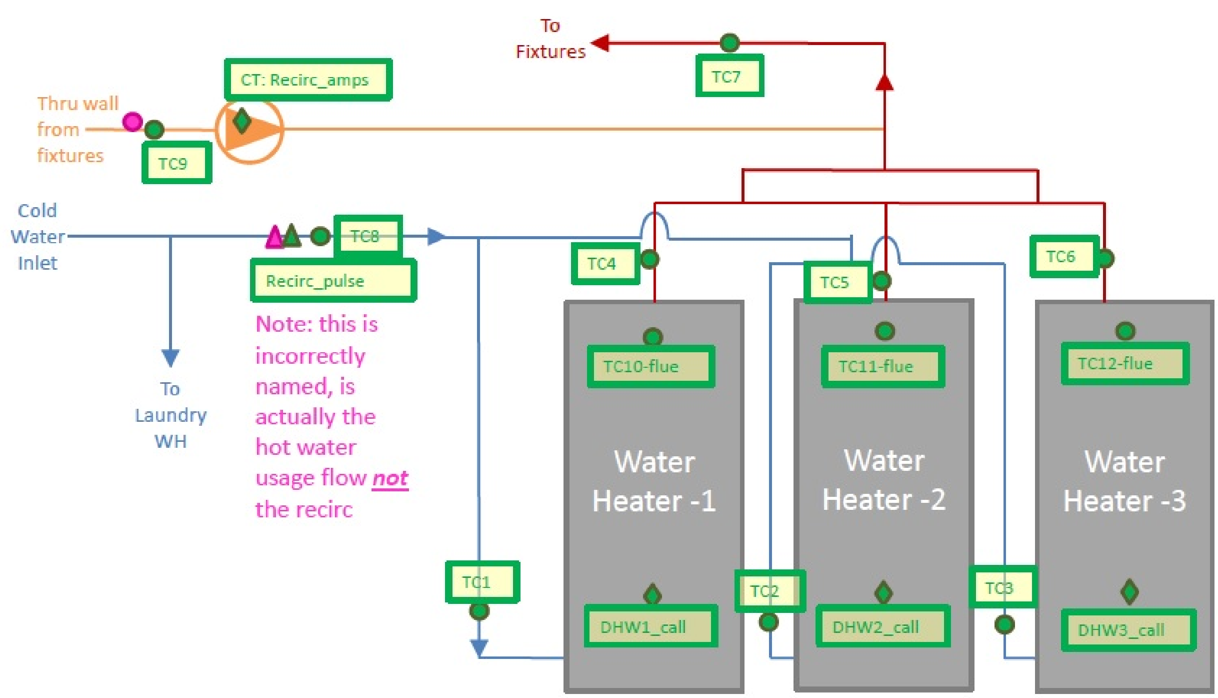
Hosp_1 Large Chain Hotel



Hosp_2 Budget Hotel



Hosp_3 Budget Hotel



Appendix B: Field Log

Hosp_01

Monitoring equipment was initially installed in April of 2016.

The properties general manager supported and approved participation in the project. The onsite contract was the head building operations for the property.

Monitoring started on the baseline system.

The demand control was installed in June 2016

Demand control operation began in early July 2016.

Initial demand control operation was not as expected. Recirculation return water temperatures were not dropping when the recirculation pump was interrupted by the control as would be expected. Buildings operation staff were hesitant to participate from early on in the project. Staff were concerned with potential issues overnight and the ramifications for building staff.

As of 7/14/16 the controller was returned to baseline mode while the controller was commissioned.

During controlled operation, the recirculation return water temperature never went below 105 ^{o}F. This prevented to controller from activating the pump to recirculate water to the hotel rooms. Building staff had a call overnight with a complaint of no hot water and had to come to the hotel to bypass the controller.

No actions were taken for several months and baseline performance continued to be monitored. The main reasons for delay were technical issues with understanding the system operation and how to fix the controller and a hesitation on the part of building staff. The overnight complaint made the initially reluctant operations staff even more hesitant, making scheduling and planning difficult.

On 2/1/17 the installing contractor returned to Hosp_01 to troubleshoot the controller issues.

One of the first options for improving controller performance was to install check valves to unintended flows and hot/cold mixing that could be the source of recirculation return water temperature to remain higher than expected, preventing pump activation.

The plumber assessed the system and determined that check valves already existed in the locations we would potentially add them. Accessing the check valves and further commissioning of the controller would have required interrupting the hot water distribution in the system. At this point building operation was not supportive of any further investigation or operation of the controller.

After the visit one 2/1/2017, project staff determined that the controller should be removed.

> The building staff were not comfortable participating in the project. The property management that was supportive of this project since early in 2017, had changed to new management in early 2017, further complicating the relationship.

Com_03

The system was installed in December of 2016.

> There were a few pre-existing issues with the systems recirculation pump. These issues were not significant under the normal operation of the system, but were emphasized when the controller was operational, turning the pump on and off more frequently than normal. For example, the pump was missing a seal that was not leaky prior to the project, but each time the pump was stopped by the controller, there was a leak. A new seal was installed, as it should have been, and the problem was solved.

Demand controller was activated 4/5/2017.

> Initial data analysis showed that the recirculation pump was still running continuously and that the controller was not operating as intended.

The building was visited by field staff on 4/18 and 4/19/2017.

> During the first visit a representative from the controller manufacturer reviewed images and data from the installation. He noticed that the temperature sensor was plugged into the wrong terminal on the controller. The sensor was fixed and the controller was activated and commissioned first in the demand mode and then in the temp only mode. Neither mode passes the commissioning test. The pump was cycling on very quickly (roughly 5-6 times in 1-2 minutes). The controller was left operational for three days until 4/22/2017 when the pump was turned to the off mode.

Recirculation pump was completely off for the weekend of 4/22/2017.

On 4/25/2017 conducted another field site visit.

> Field staff found the controller was not operational. It was switched to bsaeline mode (continuous recirculation) and the pump did not kick back on. Some additional troubleshooting found that a fuse in the controller had blown due to a surge of current in the system. The failed controller was bypassed completely and the recirculation pump was again returned in 24/7 pump operation until there the fuse could be repaired.

On 5/3/17 project staff conducted the final site visit necessary to for the controller to pass the commissioning tests and remain operational for measurement.

Project staff decided to swap out the controller completely to ensure all issues with the vlown fuse would be corrected. Additionally, the flow sensor was also replaced. A separate issue that was causing problems was the flow sensor. The tee fitting that was used for the original install did not have a large enough diameter to allow the switch to open and close freely. This caused the controller to sense flow through the recirculation loop when none was present. The tee fitting was replaced with one that has a properly sized diameter and which allowed to flow sensor to work in the manor intended.

The controller has an indicator light that flashed when flow was detected. This flow light did not come on while the recirculation pump was running and a single bathroom faucet was activated. The faucets are 0.5 GPM and don't appear to be enough flow to activate the switch

The system was left in demand mode for the rest of the project.

Hosp_02

The installation of the controller and monitoring equipment began on 7/27/2016.

The complexities of this installation required some additional controller sensors which delayed completion of the install.

The installation was complete and baseline (continuous recirculation) monitoring began 8/12/2016.

On 9/20/2016 the first control period began and 20 full days of monitored data were collected.

On 10/16/2016 project staff returned to the site to complete the first monitoring period and return to baseline mode.

Project staff returned to the site on 11/16/2016, 12/15/2016, 1/16/2017, 2/12/2017, and 3/8/2017 to alternate the operational mode.

In early march 2016 project staff was having follow up discussion with the building operations staff.

We learned that staff at the building had been deactivated the controller without informing anyone of the issues at the site. Further inquiry reviled that the hotel staff, it was learned at the first night of the 2nd operation period (11/17/2016) that the hotel received two complaints from the top two floors of the property. These complaints caused the operations staff to bypass the controller.

On 4/24/2017 project field staff went to change the controller settings in an attempt to improve the system performance.

The temperature lockout setting was changed to the maximum temperature, which meant that the controller would turn on the recirculation pump when the recirculation return water temperature dropped below 108 ^{o}F. The controller was confirmed to pass the commissioning test. The controller was turned onto demand mode, watching the pump kick off, and then taking the temperature sensor off the pipe and seeing that the pump turned on. After leaving the site, data was closely monitored and it reviled that the return temperature was being kept around 110 degrees.

On 4/25/17 hotel operations staff got a call around 5:10 am on saying that 2 people on the 4th and 5th floor were not getting hot water.

CEE project staff was unable to get any more information, but we know the building operator turned the controller to bypass around 5:30 am.

Further investigation would need to be done to determine exactly what is happening. The general consensus is that there were likely hot water crossover events happening in certain hotel rooms that are causing lower than average water temperature and causing complaints. The controller was not turned back on after 4/25/17.

Com_Ed _02

Controller and instrumentation was initially installed in spring 2016

Full data monitoring started in June of 2016

First control mode monitoring period was from 6/24/2016 to 11/15/2016.

First baseline (continuous recirculation) period was from 11/16/2016 to 1/11/2017.

On 3/8/2017 switched back to baseline mode for the 2nd period of continuous recirculation.

On 4/12/2017 switched back to controlled mode.

On 5/17/2017 switched back to the bypass or baseline mode of operation.

On this site visit, field staff found the controller's flow sensor unplugged and sitting on top of the heat exchanger. The heat exchanger in the indirect tank had been replaced roughly 3 weeks prior. The sensor was plugged back in and the system was put in bypass or baseline mode.

Com_Ed_01

4/8/2016 Successful installation was performed

The controller and monitoring instrumentation were successfully installed. The controller was activated and commissioning process was successfully completed.

Prior to May of 2017 systems was alternated between controlled and baseline modes.

Three control periods (starting 4/8/16, 11/21/16 and 3/9/17) were monitored as well as three baseline periods (starting 7/21/16, 1/17/17, and 4/12/17).

On 5/18/17 at the site visit a few issues were noticed that were not present for previous visits.

One of the thermocouples had been removed from the insulation was no longer making surface contact with the pipe. This was corrected and monitoring continued. Additionally, it was noted that the labels for TC_steam_hot and TC_hot had been mislabeled and swapped with one another. Not physical change was made. The analysis was modified to reflect the inaccurate label names.

Appendix C: Recirculation Controller Hardware

This appendix summarizes the web and literature review for demand based recirculation controllers currently available on the market.

Table 26 . Enovative Group controller summary

Manufacturer	Product	Equipment Price	Target Market	Website
Enovative Group	AutoHot™	$1,600	Single family, Multifamily, Commercial	Enovative website (http://www.enovativegroup.com/)

How it Works

A flow sensor is installed on the hot water supply that sends a signal every time a tenant demands hot water. The AutoHot also has a temp sensor placed on the return line upstream from the pump. When the temp sensor reads that the recirculation loop is above the target temp, the flow is bypassed and the pump stays off. When the recirculation loop is below target temp and the flow is triggered the pump turns on, delivering hot water to the end user.

Additional Notes

This product was formerly known as the D'MAND Circ Product. It was rebranded just prior to the start of this project.

Documented Savings

Bender, Thomas, and Doug Kosar. 2014. "Demand-Based Domestic Hot Water Recirculation." Public Project Report 1003. Nicor Gas Energy Efficiency Emerging Technology Program. Des Plaines, IL: Gas Technology Institute.

Benningfield Group. 2009. "Demand Control for Multifamily Central Domestic Hot Water." RY 2009 Monitoring Report.

Enovative Controls. n.d. "Enovative - Demand Controller - Brochure." Enovative Kontrols. http://www.enovativegroup.com/demandcontroller/.

Podorson, David. 2014. "Demand-Controlled Hot Water Recirculation Loops for Multifamily Buildings:Tests Show Consistent Energy Savings." TAS-TB-16. Boulder, CO: E Source. http://www.esource.com/system/files/files/2014-12/ESource-TAS-TB-16a-Demand-Controlled-Recirc.pdf.

Table 27. US Energy Solutions controller summary

Manufacturer	Product	Equipment Price	Target Market	Website
U.S. Energy Solutions	Hot H_2O Saver	TBD	Multifamily, Commercial, Hospitality	US Energy Solutions website http://usenergysolutions.net/hotH2Osaver.html

How it Works

This product combines a sensor, a higher speed pump, and a controller to turn the pump on and off. The sensor is placed on the cold water make-up line. When hot water leaves the tank and cold water is called to replace it, the pump activates.

Additional Notes

Their website notes "The cost of installing a flow sensor on pipes greater than 1" in diameter is excessive. A more practical solution is to create a by-pass loop where a small amount of the main flow is diverted through a smaller line and flow sensor."

Documented Savings

Product literature claims this device will cut energy costs by 23.7% or more resulting in a simple payback between 9 and 18 months. However, no further information was available.

Table 28. Faster Hot Water's controller details

Manufacturer	Product	Equipment Price	Target Market	Website
FasterHotWater.com	WaterQuick Pro II and Dedicated Recirc System	$347 - $387	Single family, Multifamily, Commercial	Faster Hot Water Website http://www.fasterhotwater.com

How it Works

The WaterQuick Pro II uses a small, high speed hot water circulation pump that's installed on the hot water outlet of a tank or tankless WH. A bridge valve connects the hot and cold water supply lines under the most remote kitchen or bath fixture. When the integrated flow manager detects hot water use, the pump is turned on. The bridge valve has a built-in temperature sensor that closes when hot water reaches the farthest sink.

The dedicated recirculation system converts an existing hot water circulation line into an on-demand delivery system by only operating the recirculation pump for a limited time (1 to 60 minutes) starting when flow is detected.

Additional Notes

Dedicated recirculation system is used most often in MF and hospitality. If there's a dedicated return line especially. Website suggests that their offering is a DIY install. The FasterHotWater controller uses a slightly different technology and approach than the previous two controllers.

With larger commercial and hospitality buildings the fixed runtime will increase the pump runtime for buildings with large DHW loads.

Documented Savings

No documented savings claims or studies. WaterQuick Pro II testimonials and testing data focus of hot water delivery speed for residential applications. Commercial/Hospitality energy savings does not appear to be a focus for this product.

The owner of the company said the dedicated Recirc System has been installed in some mid to large hotel, commercial, and multifamily buildings. However, these installations have not been documented or accessed and the installations would likely require significant additional work, as these installations have been rate to date.

Table 29. ACT Method's controller details

Manufacturer	Product	Equipment Price	Target Market	Website
ACT Metlund	D'MAND Kontrols	$646.12 - $1,369.71	Residential, Commercial	ACT Metlund Website http://www.gothotwater.com/

How it Works

This control device has many different configurations with different methods to indicate demand on the system, including automatic activation and button-triggered activation. Different series versions of the system are designed for different building sizes, pipe run lengths, and plumbing configurations.

Additional Notes

Several manufacturers offer the same basic on-demand recirculator, called the D'Mand system, which was developed by ACT Metlund. ACT Metlund sells the system online and also licenses the technology to pump manufacturer Taco and the plumbing and heating system manufacturer Uponor. This controller appears to be the Enovative AutoHot controller prior to rebranding.

Documented Savings

See Enovative AutoHot.

Table 30. Chilipepper Sale's controller details

Manufacturer	Product	Equipment Price	Target Market	Website
Chilipepper Sales	Chilipepper	$189.99	Residential, Commercial	Chilipepper website http://www.chilipepperapp.com/howit.htm

How it Works

This controller is designed to be used at the fixture level, unlike other products that are integrated within the water heating system. Typically placed under a sink, a micro-processor monitors temperature, timing, sensitivity adjustment input, and the control wire inputs and directs the pump what to do and when. When you push the start button, the Chilipepper pumps the water in a loop from the water heater to the Chilipepper, and on through the cold water piping back to the water heater inlet.

Additional Notes

This design approach addresses "trouble" fixtures far from the water heater and is focused more on improved comfort than energy savings. This is not a systematic level solution. The fixture level installation is not well suited for large scale commercial and hospitality buildings were whole system approaches are preferred.

Documented Savings

No documented or measured savings. Most case studies (ie testimonials) are focused on residential applications where reducing hot water wait time was the driving reason for installation.

Table 31. Temtrol Delta T's controller details

Manufacturer	Product	Equipment Price	Target Market	Website
Temtrol Delta T, Inc.	RedyTemp	$370 - $639	Residential. Possibly small commercial	Redy Temp Website http://www.redytemp.com/main.html

How it Works

This system is designed to be used at the end of the hot water delivery piping, such as under a remote sink. Product documentation does not specify how the demand aspect of the control works and rather focuses on the temperature measurements. It is unclear how operation of this control would differ from that on an aquastat.

Additional Notes

The website for this product seems limited. Typos, strange formatting, and low quality images suggests that this product is not from a large or professionally established business. Shortly after this initial search was conducted the product website was taken offline.

Documented Savings